Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs	)	WC Docket No. 18-89
	)	

WRITTEN *EX PARTE* SUBMISSION OF HUAWEI TECHNOLOGIES CO., LTD., AND HUAWEI TECHNOLOGIES USA, INC.

Huawei Technologies Co., Ltd., and Huawei Technologies USA, Inc. (collectively, "Huawei"), by their undersigned counsel, submit this *ex parte* presentation to the Federal Communications Commission ("FCC" or "Commission") to supplement the record in the above-captioned docket.

Huawei submits as **Attachment 1** the expert report of economist Dr. Debra J. Aron[1] analyzing the impact of excluding Huawei from the U.S. market. As the Commission is well aware, a substantial number of carriers receive some form of Universal Service Fund ("USF") support from the Commission, as do many public schools, libraries, and vendors providing e-Rate-supported services.[2] The proposed rule would prohibit Huawei from providing equipment or services to any of these carriers, who collectively account for a significant segment of the U.S.

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[1] *See* Debra J. Aron, "The Impact on the U.S. Economy of Excluding Huawei from Participation in the U.S. Market for Wireless Network Equipment," CHARLES RIVER ASSOCIATES (Oct. 7, 2019) ("Aron Report").

[2] *See Universal Service Monitoring Report*, CC Docket No. 96-45 *et al.*, Table 1.10, p. 19 (2018) (providing for $8.882 billion in USF claims for the High-Cost, Lifeline, Rural Health Care and E-Rate programs in 2017).

telecommunications market. In addition, as Huawei has already noted in the record, the stigma created by the proposed rule would discourage telecommunications carriers, both large and small, from purchasing equipment manufactured by Huawei beyond those that receive grants from the federal USF, further limiting the company's ability to participate in the U.S. market.[3] Thus, the proposed rule, as written, would have the practical effect of excluding Huawei from the U.S. telecommunications infrastructure market entirely. Additionally, barring Huawei from the U.S. market would harm the U.S. economy by delaying 5G deployment and impeding competition, resulting in both decreased employment and increased costs that will inevitably be borne by U.S. consumers. Dr. Aron's report provides the Commission with important economic data illustrating the deleterious impact that excluding Huawei from the U.S. market will have as the U.S. transitions its wireless infrastructure to support 5G technology and the services that it enables.

First, Dr. Aron details the United States' lagging position in 5G deployment as compared with the progress other countries have made. Huawei's absence from the U.S. market will only exacerbate the disparity between deployment of 5G networks in the United States and deployment of 5G networks in countries that do not bar Huawei from participating in the market. To close this gap, the United States must deploy the best telecommunications equipment available and encourage a competitive telecommunications equipment marketplace. Excluding Huawei is contrary to both of those goals. For instance, radio access network ("RAN") equipment is a crucial component of 5G networks. But, there are currently only five vendors that have the capacity to provide 5G RAN equipment to the international telecommunications marketplace at the scale that

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[3] *See* Comments of Huawei Technologies Co., Ltd. and Huawei Technologies USA, Inc., *In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, WC Docket No. 18-89 (June 1, 2018), at pp. 57-59.

will be required to support pervasive 5G deployment. As Dr. Aron demonstrates, Huawei is a market leader in the development of 5G technology and standards as a result of its significant investment in research and development.[4] Huawei's products have earned numerous industry accolades. Huawei's 5G technologies and equipment capabilities are estimated to be as much as 12-24 months more advanced than those of its competitors'. Those products include key equipment such as Massive MIMO (multiple input, multiple output) antennas, which are critical to 5G RAN deployment.

Second, Dr. Aron examines the impact of delayed 5G deployment on the U.S. economy and the established relationship between telecommunications technology—in particular, mobile broadband technology—and gross domestic product ("GDP"). The Commission has consistently recognized that "5G is critical to [the U.S.] economy, security and quality of life . . . ."[5] Accenture projects that the direct economic benefits associated with 5G will be substantial – "U.S. telecom operators could invest approximately $275 billion over seven years to deploy next-generation wireless technology[,]" could result in the creation of 3 million jobs, and may result in GDP growth of approximately $500 billion.[6] Studies illustrate that delays in technology penetration dampen GDP growth.[7] Expedient 5G deployment, in contrast, would directly benefit the U.S. economy by

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4 *See* Aron Report at Section VII.A

5 Remarks of FCC Chairman Ajit Pai, National Spectrum Consortium 5G Collaboration Event, Arlington, Virginia (Apr. 30, 2019).

6 Al Amine, Majed, Kenneth Mathias, and Thomas Dyer. "Smart Cities: How 5G Can Help Municipalities Become Vibrant Smart Cities." ACCENTURE STRATEGY, 2017 at p.11, available at: https://newsroom.accenture.com/content/1101/files/Accenture_5G-Municipalities-Become-Smart-Cities.pdf (last visited Sept. 30, 2019).

7 *See, e.g.*, Aron Report at para. 150 (citing Jerry Hausman, "Valuing the Effects if Regulation on New Services in Telecommunications," Brookings Papers: Microeconomics (1997)).

stimulating carrier expenditures and generating the jobs necessary for rolling out 5G infrastructure.[8] Rapidly deploying 5G networks also would indirectly benefit the U.S. economy by facilitating the development and distribution of innovative goods and services within the 5G ecosystem.[9] This effect would accelerate as U.S. consumers grow increasingly dependent on devices that are part of the Internet of Things. Indeed, the delay in 5G deployment resulting from the unavailability of mid-band spectrum is already costing the U.S. economy.[10] Dr. Aron calculates that the further delay resulting from excluding Huawei from the U.S. market could result in *additional* losses to the U.S. economy from approximately $104 billion to $241 billion.[11]

Third, Dr. Aron discusses the effect that delayed 5G deployment will have on U.S. employment by directly reducing the number of available jobs in industries related to the rollout of 5G networks, including but not limited to manufacturing, construction, and engineering. Job losses in these "direct" industries will cause further reduced employment in industries that typically supply inputs to "direct" industries, such as support jobs at restaurants and grocery stores

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[8] *See, e.g.*, Dan Littmann, Phil Wilson, Craig Wigginton, Brett Haan, and Jack Fritz. "5G: The Chance to Lead for a Decade," DELOITTE, 2018 at p.11, available at: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/technology-media-telecommunications/us-tmt-5g-deployment-imperative.pdf (last visited Sept. 30, 2019).

[9] *See id.* at 9-11; *see also, e.g.*, "The 5G Era: Age of Boundless Connectivity and Intelligent Automation," GSMA, 2017, available at: https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download (last visited Sept. 30, 2019); Steve Lo and Kevin Lee, "China is Poised to Win the 5G Race: Key Steps Extending Global Leadership," ERNST & YOUNG, 2018 at pp. 27-35, available at: https://www.ey.com/Publication/vwLUAssets/ey-china-is-poised-to-win-the-5g-race-en/$FILE/ey-china-is-poised-to-win-the-5g-race-en.pdf (last visited Sept. 30, 2019).

[10] *See* Aron Report at Section V.B, para. 79 ("The United States is therefore at a material disadvantage in competing for leadership in 5G deployment with countries in which mid-band spectrum has already been allocated (e.g., China, Japan, and South Korea), while in the United States mid-band spectrum is unavailable to three of the four top carriers and no clear timeline for its allocation has been established.").

[11] *See* Aron Report at para. 186.

that may cater to construction and related activities. Dr. Aron's quantitative analysis predicts that delayed 5G investment caused by Huawei's exclusion in the U.S. market would cause, at minimum, a loss of 25,200 jobs in 2019, and up to an additional 50,300 jobs lost in 2020.[12]

Finally, Dr. Aron analyzes how excluding Huawei from the United States market would reduce competition in the 5G equipment market and therefore impose increased costs on carriers and consumers. In turn, that reduced competition would further result in reduced deployment of 5G networks in less urban areas, where the potential economic returns on 5G infrastructure investment are less certain. Specifically, the U.S. market for RAN equipment is already overly concentrated, with an estimated Herfindahl–Hirschman Index ("HHI") concentration measure of between 2,964 and 3,125—and an HHI above 2,500 indicates a highly concentrated market. Yet excluding Huawei would elevate this number to 4,071. U.S. Department of Justice and Federal Trade Commission Guidelines predict that such a significant increase enhances existing participants' market power, causes prices to rise, and damages social welfare.[13] In fact, Dr. Aron estimates that Huawei's absence from the U.S. market will result in 12.6-16% higher weighted average prices for RAN equipment than if Huawei were not excluded.[14] Conversely, allowing Huawei to compete in the U.S. market would not only generate substantial downward pricing pressure on Huawei's competitors, but also encourage Huawei's competitors to develop more innovative products.[15] That additional competition and price reduction would help to close the

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12 *See* Aron Report at para. 194.

13 *See* U.S. Dep't of Justice & Fed. Trade Comm'n, Horizontal Merger Guidelines § 5.3, at 18-19 (Aug. 19, 2010), available at https://www.justice.gov/sites/default/files/atr/legacy/2010/08/19/hmg-2010.pdf (last visited Sep. 30, 2019).

14 *See* Aron Report at para. 213.

15 *See id.* at para. 218.

broadband divide by encouraging carriers to deploy 5G equipment more broadly and quickly, particularly to the benefit of rural areas where challenging economies of scale make access to competitively priced equipment essential to the business and investments case to rollout 5G networks.

The Commission's proposed rule will have a disproportionately negative affect on rural economies and the lives of rural Americans. The Commission recognizes that the myriad benefits accompanying broadband access—such as employment and educational opportunities, innovations in health care and telemedicine, and connectivity among families and communities—can be "even more important in America's more remote small towns, rural, and insular areas."[16] This is particularly true with respect to 5G deployment, which has been widely regarded as a "digital revolution" capable of providing transformative technological solutions for Americans across the country.[17] Indeed, Commission leadership has repeatedly acknowledged the importance of 5G networks for rural Americans.[18] But many communities in rural America already fear that

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[16] *Connect America Fund, ETC Annual Reports and Certifications, Establishing Just and Reasonable Rates for Local Exchange Carriers, and Developing a Unified Intercarrier Compensation Regime,* Report and Order, Third Order on Reconsideration, and Notice of Proposed Rulemaking, WC Docket No. 10-90 *et al*., (rel. Mar. 23, 2018) at para. 2.

[17] *See, e.g.,* Remarks of FCC Chairman Ajit Pai, National Spectrum Consortium 5G Collaboration Event, Arlington, Virginia (Apr. 30, 2019) (highlighting that "5G will power smart transportation networks that reduce traffic, prevent accidents, and limit pollution. 5G will enable healthcare professionals to remotely monitor your health and transmit data to your doctor before problems become emergencies. 5G will empower farms to apply precision agriculture. And, of course, 5G will unlock innovations that are yet to be imagined.").

[18] *See, e.g.,* Remarks of FCC Chairman Ajit Pai at the White House, Washington, D.C. (Apr. 12, 2019) ("The second reason U.S. leadership matters is that 5G will improve Americans' lives in so many ways. From precision agriculture to smart transportation networks to telemedicine and more, we want Americans to be the first to benefit from this new digital revolution, while protecting our innovators and citizens. And we don't want rural Americans to be left behind."); Remarks of FCC Commissioner Brendan Carr, "Grassroots Leadership on 5G", Indianapolis, Indiana (Sep. 4, 2018) at 2 ("When I think about success—when I think about winning the race to 5G—the finish line is not the moment we see next-gen

"they may be left behind" when it comes to 5G deployment.[19] The proposed rule will only serve to widen the digital divide in rural areas. Rural carriers providing services to remote or underserved areas of the United States, where adequate communications services are already scarce, depend especially on USF support due to challenging economies of scale in areas that lack dense populations.[20] As the record demonstrates, some rural carriers may be entirely unable to sustain operations under the proposed rule.[21] Adopting policies that increase carriers' costs to deploy 5G networks will not only increase corresponding costs charged to rural consumers, but will result in disproportionate delays to rural communities in the deployment of 5G network infrastructure itself. This, in turn, will slow the "virtuous cycle" where deploying broadband networks spurs new uses and applications of such technology, fostering increased demand for such networks, leading to increased investment in such networks, and refreshing the cycle.[22]

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deployments in New York or San Francisco. Success can only be measured when all Americans, no matter where they live, have a fair shot at fast, affordable broadband.").

[19] Remarks of FCC Commissioner Brendan Carr, "Grassroots Leadership on 5G", Indianapolis, Indiana (Sep. 4, 2018).

[20] *See Multi-Association Group Plan for Regulation of Interstate Services of Non-Price Cap Incumbent Local Exchange Carriers and Interexchange Carriers et al.*, Second Report and Order and Further Notice of Proposed Rulemaking, Fifteenth Report and Order and Report and Order, CC Docket No. 96-45 *et. al*, 16 FCC Rcd 19613, 19617, para. 4 (2001) (recognizing that smaller carriers "generally have higher operating and equipment costs ... due to lower subscriber density, smaller exchanges, and limited economies of scale").

[21] *See, e.g.,* Comments of the Rural Broadband Alliance, *Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs,* WC Docket No. 18-89 (June 1, 2018), at 14 (labeling the proposed rule as "an existential threat to the entire business"); Comments of the Mark Twain Telephone Company, *Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, WC Docket No. 18-89 (June 1, 2018), at 3-4 ("the costs associated with the replacement of existing equipment … impos[e] a significant and unreasonable financial burden on rural telecommunications companies").

[22] *See, e.g.,* Remarks of FCC Chairman Ajit Pai, Mobile World Congress Americas, San Francisco, California (Sept. 12, 2017) (discussing the need to "close the digital divide and boost network investment" with "an eye toward revving the virtuous cycle of faster, better networks that unleash new innovations that drive additional consumer demand").

Huawei urges the Commission to consider carefully the substantial harms its proposed rules would inflict on U.S. carriers, consumers, and the economy; and whether there are less costly and more effective means available to achieve its network security goals. Huawei stands ready to work with the Commission to develop a vendor-independent, supply-chain cybersecurity process like that recommended by the National Institute of Standards and Technology.[23] As Huawei has previously noted, a number of U.S. Government officials support a vendor-agnostic approach to supply chain security, and many U.S. allies, including Germany, France, the United Kingdom, and Canada, have also expressed a desire for a holistic approach to managing risk in the telecommunications supply chain. [24]

Huawei recognizes the importance of creating secure telecommunications networks. But the Commission's proposed rule does not do so. Instead, it only serves to exacerbate the widening gap in 5G deployment between the United States and other countries. Dr. Aron demonstrates that delayed 5G deployment will impair the U.S. economy by depressing competition and reducing available jobs to U.S. workers. Moreover, these harms will be felt greatest by Americans in rural and undeserved areas. The Commission should support a comprehensive, holistic approach to supply-chain security based on existing best practices instead of focusing on proscriptions based on vendor's country of origin that would do little to advance supply-chain security. Moreover, as

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[23] *See* National Institute for Standards and Technology, Framework for Improving Critical Infrastructure Cybersecurity, Ver 1.1 (Apr. 16, 2018) available at https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.04162018.pdf (last visited Sept. 30, 2019); National Institute for Standards and Technology, Supply Chain Risk Management for Federal Information Systems and Organizations, NIST Special Publication 800-161 (2015) available at https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-161.pdf (last visited Sept. 30, 2019).

[24] *See* Written Ex Parte Submission of Huawei Technologies Co., Ltd and Huawei Technologies USA, Inc., *Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, WC Docket No. 18-89 (Jul. 12, 2019) at pp. 5-8.

the Commission considers adopting rules and policies to ensure the integrity of U.S. communications networks, it must do so in a targeted manner consistent with established best practices in order to avoid delaying 5G deployment, hindering competition and negatively impacting employment in the United States.

Respectfully submitted,

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October 11, 2019

ATTACHMENT 1

"The Impact on the U.S. Economy of Excluding Huawei from Participation in the U.S. Market for Wireless Network Equipment"

The Impact on the U.S. Economy of Excluding Huawei from Participation in the U.S. Market for Wireless Network Equipment

EXPERT REPORT

of

Dr. Debra J. Aron
Charles River Associates
October 7, 2019

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I. QUALIFICATIONS

1. My name is Debra J. Aron. I am a Vice President at Charles River Associates ("CRA"). CRA is an international consulting and expert services firm that provides, among other services, economic expertise for litigation, regulatory proceedings, policy debates, and business strategies.

2. I received a Ph.D. in economics from the University of Chicago in 1985, where my honors included a Milton Friedman Fund fellowship, a Pew Foundation teaching fellowship, and a Center for the Study of the Economy and the State dissertation fellowship.

3. From 1985 to 1992, I was an Assistant Professor of Managerial Economics and Decision Sciences at the J. L. Kellogg Graduate School of Management, Northwestern University. Concurrent with my position at Northwestern University, I also held the position of Faculty Research Fellow with the National Bureau of Economic Research from 1987 to 1990.

4. I was named a National Fellow of the Hoover Institution, a think tank at Stanford University, for the academic year 1992-1993, where I studied innovation and product proliferation in multiproduct firms. From 1993 to 1995, I was a Visiting Assistant Professor of Managerial Economics and Decision Sciences at the Kellogg School. At the Kellogg School, I taught M.B.A. and Ph.D. courses in managerial economics, information economics, the economics and strategy of pricing, and the economics of competitive strategy.

5. I continued to teach economics and business strategy as an Adjunct Associate Professor in the Masters of Science in Communications program at Northwestern University in most years between 2000 and 2016. In that program I taught a graduate course in economics and competitive strategy with a focus on communications markets.

6. I am a member of the American Economic Association and the Econometric Society and an associate member of the American Bar Association. I have published scholarly articles on innovation, competition, incentives, and pricing in several leading academic journals, including the American Economic Review, the RAND Journal of Economics, and the

Journal of Law, Economics, and Organization. I am co-author of the economics chapter of the American Bar Association's Section of Antitrust Law Telecom Antitrust Handbook.

7. Much of my consulting and scholarly work in the last twenty years has pertained to the telecommunications industry. My work has included economic analysis for litigation, regulatory disputes, public policy, merger analyses, and business consulting. Areas of analysis have involved wireless telephony, wireline telecommunications, broadband, and satellite communications and retail, wholesale, and equipment markets. I have written, testified, and published scholarly work on matters related to the demand for and the costs of advanced telecommunications services. I am familiar with and have examined the costs, revenues, networks, subscribers, usage, and other data of telecommunications companies. Telecommunications and technology matters in which I have testified have included class actions, contract disputes, antitrust litigation, mergers, regulatory proceedings, arbitrations, and intellectual property matters. My clients have included numerous telecommunications companies in the United States and abroad, including both large and small wireless telecommunications companies and telecommunications equipment companies.

8. I have submitted evidence to the U.S. Federal Communications Commission ("FCC") regarding, among other topics, the measurement of competition and market power in telecommunications markets and telecommunications pricing and costing standards. My scholarly work has been cited by the FCC. I have also testified in a number of states on regulatory issues pertaining to broadband markets, broadband deployment, and incentives for broadband investment.

9. My professional qualifications are further detailed in my curriculum vitae, which is attached as Exhibit I.1 to this report.

10. I have prepared this report at the request of Huawei Technologies Co., Ltd, and have been compensated by Huawei for my work. This report represents my independent assessment and opinions.

II. Summary of Conclusions

11. The development and production of wireless infrastructure equipment is a highly technical and research-intensive business, yet it is critical to the ability of wireless telecommunications carriers to deploy new, ground-breaking technologies. There are only five companies worldwide that have demonstrated the expertise and capabilities to be in that business, and only three have significant shares of global sales. Even among that limited group, Huawei Technologies Co., Ltd. ("Huawei") is the leader in equipment sales, research and development ("R&D") spending, product performance, patent production for the newest technology, and several other metrics that demonstrate its worldwide leadership role as a premier provider of the equipment required to deploy advanced and innovative wireless networks.[1]

12. The exclusion of Huawei from the opportunity to compete in the U.S. market has harmed the U.S. economy and will, if continued, substantially impede the ability of the United States to achieve its goal of leadership in the deployment of the newest network technology now being rolled out worldwide, known as "5G." 5G technology is expected to not only provide massive capacity, speed, and latency improvements over existing wireless technology, but to transform many existing industries and create new ones. 5G technology is anticipated to enable innovation in transportation, logistics, the Internet of Things ("IoT"), electricity distribution, public safety, and health and wellness, among others.

13. Economic studies have found that adoption of new wireless technologies translates into real economic benefits for a country. Several studies find that the global leaders in previous generations of wireless networks were awarded greater macroeconomic benefits, including job creation and increased gross domestic product ("GDP"), than non-leading countries. These benefits arise through the development of a wireless ecosystem of new products and services that support and are supported by the new technology.

[1] I understand that among the Huawei entities, Huawei Technologies Co., Ltd., a wholly owned subsidiary of the Huawei Investment & Holding Co., Ltd., is the entity primarily responsible for "development, manufacture and sale of telecommunication and related products and provision of support and maintenance services." See Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 123.

14. Huawei has developed differentiated expertise relative to other vendors of 5G equipment. One of the key technologies deployed in 5G networks is Massive MIMO, which is a multiple input, multiple output active antenna system. Massive MIMO is based on a technology in which, for historical reasons, Huawei had developed exceptionally extensive expertise and experience. Perhaps as a result, Huawei has by far the largest revenue share in the market for Massive MIMO. The evidence indicates, and multiple industry participants have concluded, that Huawei has the most advanced Massive MIMO products available in the market today.

15. Huawei is also considered a leader in 5G radio access network ("RAN") equipment overall based on (1) baseband unit ("BBU") capacity, (2) breadth of its radio unit ("RU") portfolio, (3) ease of installation, and (4) ease of upgrade from 4G to 5G. A recent report by market research firm GlobalData found Huawei's 5G RAN equipment to lead in every category considered.[2]

16. The United States is already behind other leading countries in the "race" to 5G, as measured by early expenditures on 5G equipment. Access to the most advanced and most accepted equipment available is particularly important in the United States because of what is sometimes referred to as the U.S. spectrum "gap." Spectrum bands in the mid-frequencies ("mid-band spectrum") are necessary for economical nationwide broad-based deployment of 5G. In the United States, however, significant mid-band spectrum has not yet been made available for mobile use, and three of the four major U.S. wireless carriers currently lack access to any portion of mid-band spectrum. Most of the countries around the world already planning, testing, or deploying 5G networks are using mid-band spectrum.[3]

17. U.S. carriers, in contrast, are conducting initial deployments largely in other spectrum bands that may be appropriate for certain uses (primarily, either fixed wireless broadband replacement, or very high-density locations) but not for large scale mobile deployment.

18. The spectrum gap has already delayed 5G deployment and adoption in the United States compared to other leading countries that have successfully deployed and launched 5G

[2] See Section VII.B.
[3] See Section V and Appendix D.

networks. The absence of Huawei—a technology leader in 5G RAN in general and in Massive MIMO in particular—from the U.S. market for 5G RAN equipment will inevitably damage the United States' ability to regain lost ground to the extent it is possible once mid-band spectrum is finally allocated, and cause additional delays in 5G deployment and adoption.

19. In addition, exclusion of Huawei from the U.S. market is likely to work to the detriment of 5G service quality in the United States relative to that in other countries. History has shown that despite its early adoption of 4G technology, the United States—in which Huawei has never had a material sales share—has far slower networks than dozens of countries in Europe, Asia, and the rest of the world, all regions where Huawei is the largest equipment vendor.

20. I have estimated the effect on the U.S. economy of a delay in 5G deployment and adoption that would be associated with continued absence of Huawei from the U.S. market. I estimate that the present discounted value of losses to U.S. GDP would vary from approximately $104 billion (for a 6-month delay) to approximately $241 billion (from an 18-month delay), over and above the effects on the U.S. economy associated with the delay in 5G deployment caused by the spectrum gap in the United States. In addition, I estimate that delayed infrastructure investment due to the absence of Huawei would depress employment by 25.2 thousand jobs in 2019 and by up to 50.3 thousand jobs in 2020, depending on the duration of delay.

21. The absence of Huawei from the U.S. market would also be expected to weaken competition in a highly concentrated marketplace in which, by the most recent statistics, almost 90 percent of sales of radio access network equipment was provided by only two companies, Nokia and Ericsson. I estimate that the absence of Huawei in the U.S. market for RAN equipment has materially increased market concentration, resulting in prices for RAN equipment that are 12.6-16.0 percent higher on a weighted average basis than they would be with the competition provided by Huawei. An increase in prices of 12.6-16.0

percent is considered material and harmful to social welfare.[4] I would expect some, if not all, of this increase in carriers' costs of building and upgrading their networks to be passed through in the form of higher prices for wireless services paid by consumers, businesses, and the government. Further, it will likely prompt wireless carriers to deploy less 5G infrastructure in rural and other areas where the business case for deployment may be marginal.

22. This analysis does not include the cost to consumers, businesses, and government customers of depressed incentives of other vendors to intensify their R&D efforts and of inferior network performance that would be expected from excluding from the market for 5G RAN equipment the vendor that is demonstrably the most technologically accomplished.

III. PURPOSE OF THIS REPORT

23. I understand that in 2018, the FCC initiated this proceeding to consider whether to adopt a rule that would have the effect of prohibiting the use of universal service funds for the purchase of equipment or services from providers identified as posing a national security risk.[5] The FCC specifically identified Huawei as a company that it evidently considers a candidate to be designated as a supplier to which that prohibition would apply.[6]

24. Huawei's presence in the U.S. market for RAN equipment has been very limited for several years, reportedly as a result of several policy and political interventions.[7] Continuing to limit Huawei's presence in the United States and imposing additional restrictions would prevent Huawei from becoming a competitor and supplier on a level playing field with the other major global providers of RAN equipment who supply carriers in the United States. Indeed, I understand most of Huawei's business as a telecommunications equipment

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[4] See Section IX.

[5] See Notice of Proposed Rulemaking, *In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, Before the Federal Communications Commission, WC Docket No. 18-89, FCC 18-42 (Released: April 18, 2018), ¶ 2.

[6] See Notice of Proposed Rulemaking, *In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, Before the Federal Communications Commission, WC Docket No. 18-89, FCC 18-42 (Released: April 18, 2018), ¶¶ 4-6.

[7] See Section VI for a more detailed discussion of these political and policy interventions.

supplier in the United States is to universal service fund recipients and, thus, barring use of such funds for purchase of Huawei equipment might well have the practical effect of excluding Huawei from the U.S. market.

25. I have been asked by Huawei to assess the economic effects on the U.S. marketplace and economy of excluding Huawei from selling its products and services in the United States. In this report I quantify the effects on the price of telecommunications network equipment, GDP, and employment of excluding Huawei from the opportunity to provide RAN telecommunications equipment in the United States. All analyses conducted and opinions expressed in this report are my own, independent of the interests or opinions of Huawei or any other entity. The data used in this report to support my opinions are also independent, third-party data not provided by Huawei.

26. Excluding Huawei from the United States has already had and will continue to have significant economic effects. I analyze two significant avenues of economic effects in this report. One avenue of economic impact from banning Huawei from the U.S. marketplace is that excluding any of the major global vendors of wireless network equipment will dampen competition that benefits U.S. wireless services suppliers and consumers. Equipment vendors compete to provide wireless carriers with the best combination of price, quality, and product features. As I will discuss, there are only a few companies that offer RAN infrastructure equipment, and even fewer that make large, ongoing investments in R&D for that equipment. Excluding one of those market participants from competition dampens competition in the provision of network equipment in the United States and results in higher equipment prices paid by U.S. wireless carriers.

27. But perhaps even more importantly and more urgently, continuing to exclude Huawei from the United States is particularly damaging because the United States—and the world—are at the inception of a transition to the next and most advanced wireless technology. Known as 5G ("fifth generation"), this technology is expected to transform the way we live and work. Because certain spectrum bands critical for 5G deployment are currently not available to three out of four major U.S. carriers, the deployment of 5G networks has already been delayed in the United States, and the United States is already behind other

countries in 5G network investment. Excluding Huawei from the United States is likely to further delay the United States' deployment and adoption of 5G, with ripple effects throughout the economy. These effects are the primary focus of my report.

28. This report concentrates on the components of wireless networks known as the Radio Access Network, or "RAN." A wireless network generally consists of the RAN, the core network, and other components providing transport between the RAN and the core. The RAN is responsible for the radio-related functionality of the network, including transmitting signals between the users' handsets and the core network, while the core network's main functionality is to manage and route voice and data traffic between the RAN and other data networks, such as the internet. RAN equipment includes antenna systems and base stations that transmit and receive the signals. Core equipment includes routers and switches.[8] I focus on the 5G RAN components because the 5G RAN is generally being deployed first in order to enable and operationalize a new generation of technology, while relying on the existing core and upgrading it later.[9] Accordingly, the economic impact of the delay caused by the inability to use Huawei equipment in the United States would be experienced first with respect to its RAN equipment.

29. This report does not offer any opinion on national security aspects, if any, of Huawei's telecommunications network equipment.

IV. BACKGROUND

A. The Evolution of Wireless Telecommunications Technology

30. The rapid and transformative developments of wireless communications technologies over the last four decades have been categorized into five "generations."

[8] See REGULATION (EC) NO 139/2004 MERGER PROCEDURE: ARTICLE 6(1)(B) NON-OPPOSITION, "Case No COMP/M.7632 – NOKIA/ALCATEL-LUCENT," July 24, 2015 (hereafter, *Nokia/Alcatel-Lucent Merger Procedure 2015*), pp. 2, 3, 8-9.

[9] Irina Cotanis, "5 Critical 5G Network Deployment Challenges," Infovista Blog, August 15, 2019, at https://www.infovista.com/blog/5g-network-deployment-challenges?utm_source=facebook&utm_medium=update.

31. The first country to launch a first generation ("1G") commercial network was Japan in 1979. 1G was an analog system and offered no data capabilities—that is, it was a voice-only communications system.[10] Despite its limited capabilities and capacity, 1G analog wireless technology ushered in a new era in which telephony was not confined to a wireline phone, allowing voice communications to go mobile.

32. The limitations of analog wireless telephony soon became apparent. Analog systems make very inefficient use of spectrum, so that a given amount of spectrum could support a relatively small volume of telephone calls[11] and calls were therefore very expensive.[12] In response to the economic and technical limitations of 1G technology, the second generation ("2G") of wireless technology emerged in the late 1980s and was the first digital wireless technology.[13] Digital technology not only allowed much more efficient use of spectrum, thereby supporting much higher call volumes and reducing the cost of service, but it also enabled certain basic data services, such as texting.[14]

33. There were several versions of 2G technology that used different technology standards.[15] Two of the major 2G standards worldwide were Global System for Mobile Communications ("GSM") and IS95 Code Division Multiple Access ("CDMA").[16] Europe coordinated on a single standard—GSM—which was endorsed by the European Council

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[10] Prasant Kumar Pattnaik and Rajib Mall, FUNDAMENTALS OF MOBILE COMPUTING (PHI Learning Pvt. Ltd., 2015), p. 32. See also, Lopa J. Vora, "Evolution of Mobile Generation Technology: 1G to 5G and Review of Upcoming Wireless Technology 5G," *International Journal of Modern Trends in Engineering and Research* 2, iss. 10 (October 2015) (hereafter, *Vora 2015*), p. 281.

[11] *Vora 2015*, pp. 281-282.

[12] Prasant Kumar Pattnaik and Rajib Mall, FUNDAMENTALS OF MOBILE COMPUTING (PHI Learning Pvt. Ltd., 2015), p. 34.

[13] The first 2G network was launched in Finland in 1991. Ilya Grigorik, HIGH PERFORMANCE BROWSER NETWORKING (O'Reilly Media, Inc., 2013) (hereafter, *Grigorik 2013*), at https://hpbn.co/mobile-networks; and *Vora 2015*, p. 282.

[14] *Vora 2015*, p. 282; Jeffrey L. Funk and David T. Methe, "Market- and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication," *Research Policy* 30, no. 4 (2001) (hereafter, *Funk and Methe 2001*), p. 593.

[15] *Grigorik 2013*. Technology standardization is the process of creating systems, products, and services within a set of guidelines. Developing a new telecommunications technology standard involves a number of parties, including telecommunications equipment vendors, carriers, users, interest groups, and governments. Standardization helps to ensure systems' interoperability, safety, quality, and repeatability. "Setting the standard," Ericsson, at https://www.ericsson.com/en/future-technologies/standardization.

[16] *Funk and Methe 2001*, pp. 600-601. For the definition of GSM, see *Grigorik 2013*.

and which was adopted by most European carriers.[17] The United States, however, took a more laissez-faire approach and, rather than orchestrating the adoption of one standard, left each carrier to select the standard it preferred.[18]

34. AT&T Wireless adopted a standard known as Time Division Multiple Access ("TDMA"), which was closely related to GSM.[19] T-Mobile (formerly VoiceStream Wireless) adopted the GSM standard.[20] Sprint and Verizon Wireless, however, were among the relatively few major carriers in the world to adopt CDMA.[21]

35. Researchers have argued that Europe's coordination on a single telecommunications standard facilitated deployment by reducing carriers' uncertainty in committing to the GSM standard and allowing European countries to launch 2G networks ahead of other countries.[22] In the United States, the lack of coordination on a single standard is thought to have created uncertainty among U.S. carriers over which standard to adopt, retarding the widespread adoption of 2G networks in the United States.[23]

36. There are several factors that determine successful dissemination of a new technology standard such as GSM or CDMA. One is whether a large number of carriers adopt it. When many carriers adopt a technology, equipment vendors (which include network equipment suppliers and handset suppliers) have a greater incentive to manufacture standard-specific equipment. The more vendors that produce equipment for that standard,

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[17] *Funk and Methe 2001*, p. 600; Rudi Bekkers, Geert Duysters, and Bart Verspagen, "Intellectual property rights, strategic technology agreements and market structure: The case of GSM," *Research Policy* 31 (2002) (hereafter, *Bekkers et al. 2002*), p. 1145, fn. 5.

[18] *Funk and Methe 2001*, pp. 600-601.

[19] Jerry Hausman, "Mobile Telephone," in HANDBOOK OF TELECOMMUNICATIONS ECONOMICS, VOLUME 1: STRUCTURE, REGULATION AND COMPETITION, eds. Martin E. Cave, Sumit K. Majumdar, and Ingo Vogelsang (Amsterdam: Elsevier Science B.V, 2002) (hereafter, *2002 Hausman*), p. 568. For the definition of TDMA, see *Funk and Methe 2001*, p. 601.

[20] Seventh Report, *In the Matter of Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993; Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services*, Before the Federal Communications Commission, FCC 02-179 (Released: July 3, 2002) (hereafter, *7th CMRS Report*), fn. 61 and Section II.A.1.c.i.

[21] *2002 Hausman*, pp. 568-570.

[22] "How America's 4G Leadership Propelled the U.S. Economy," Recon Analytics, April 16, 2018 (hereafter, *Recon Analytics Report 2018*), p. 3; *Funk and Methe 2001*, pp. 600, 603-604.

[23] *Funk and Methe 2001*, pp. 600-601; *Recon Analytics Report 2018*, p. 3.

the more competition there is, which in turn results in lower equipment prices.[24] The greater the availability of equipment and handsets and the lower the prices, the more attractive the standard is to carriers who have not yet adopted a standard.[25] This creates a virtuous cycle that reinforces the success of the standard.

37. The industries that arise from the development of new wireless technologies, including handsets, applications, advertising, and other businesses that leverage the unique capabilities of wireless technologies, are collectively referred to as the wireless ecosystem.[26] Each development of a new generation of technology triggers economic development directly by growing the revenue opportunities of the wireless services providers, but also indirectly by encouraging innovation in other sectors of economy.

38. The United States was indeed very slow to develop 2G networks relative to the rest of the world. For example, in December 1994, Germany's 2G penetration rate (the percentage of the population that subscribed to 2G technology) was 71 percent, while the United States' 2G penetration rate was only 0.1 percent. The United States did not reach even 50 percent 2G penetration until 1999, at which point Japan, France, Germany, Italy, Spain, and the United Kingdom all had 2G penetration rates of over 90 percent, and most were close to 100 percent.[27] The United States did not catch up to the 2G penetration in other countries until nearly a decade after it began deploying 2G, at which point the other countries' 2G penetration rates were largely in decline as they had begun to deploy the third generation of mobile communications, "3G."[28]

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[24] For example, when many carriers committed to GSM standard, this relieved suppliers' uncertainty about the potential market size for this standard and provided suppliers incentives to produce equipment for GSM. *Bekkers et al. 2002*, pp. 1145-1146.

[25] *Funk and Methe 2001*, p. 603.

[26] *2019 Global Race to 5G Analysys Mason Report*, p. 4, fn. 2.

[27] *Recon Analytics Report 2018*, pp. 3-4 and Exhibit 1.

[28] *Recon Analytics Report 2018*, pp. 3-4 and Exhibit 1.

39. 3G technology emerged around 2001 in Japan[29] and was the first true step to high-quality mobile broadband.[30] There were, again, two main competing 3G standards, which were the separate evolution paths of GSM and CDMA. Universal Mobile Telecommunication System ("UMTS"), also referred to as wideband CDMA ("WCDMA"),[31] was developed based on the GSM standard, and CDMA2000 was developed based on the CDMA standard.[32] A third 3G standard, Time Division-Synchronous Code Division Multiple Access ("TD-SCDMA"), which used Time Division Duplex technology, was developed and used in China.[33] High-Speed Download/Upload Packet Access ("HSPA") was an evolution of the UMTS 3G standard introduced in the early 2000s.[34]

40. Once again, the United States was very late to adopt the new technology relative to the rest of the world and especially relative to the 3G leader, Japan. In 2007, U.S. penetration of 3G was less than 10 percent, at which point Japan already had over 50 percent 3G penetration.[35]

41. To address the ever-increasing demand for higher data transmission speeds and lower latencies,[36] the 3rd Generation Partnership Project ("3GPP"), an organization responsible for the development of 3G and subsequent technologies,[37] redesigned the core and radio network technologies.[38] That effort led to the creation of the fourth generation ("4G") of

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[29] Prasant Kumar Pattnaik and Rajib Mall, FUNDAMENTALS OF MOBILE COMPUTING (PHI Learning Pvt. Ltd., 2015), p. 36.

[30] Erik Dahlman, Stefan Parkvall, Johan Sköld, 5G NR: THE NEXT GENERATION WIRELESS ACCESS TECHNOLOGY (Academic Press, 2018) (hereafter, *Dahlman et al. 2018*), p. 1.

[31] "What is 3G UMTS: WCDMA Tutorial," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/3g-umts/what-is-umts-wcdma-tutorial.php.

[32] *Grigorik 2013*.

[33] "What is 3G TD-SCDMA," Electronics Notes, at https://www.electronics-notes.com/articles/connectivity/3g-umts/td-scdma.php.

[34] *Grigorik 2013*.

[35] Recon Analytics Report 2018, Exhibit 2.

[36] Low latency is important for real-time application and "streaming" applications such as video, for example. I provide a definition of latency in Section IV.B.

[37] *Grigorik 2013*.

[38] Radio access and core networks are fundamental parts of telecommunications networks. I define them later in this section.

mobile communications networks in 2008. 4G was deployed in large part through the Long Term Evolution ("LTE") standard.[39]

42. Unlike the previous generations of digital wireless technology, LTE was not bifurcated into a GSM evolution path and a CDMA evolution path. Rather, LTE was on the evolution path for both technologies.[40] All major carriers in the United States adopted LTE as their 4G technology.[41] LTE supports both time division duplex ("TDD") and frequency division duplex ("FDD") schemes.[42] I explain the difference between TDD and FDD, and their relevance to the current 5G transition, in Section VII.C. Most LTE networks adopted in the United States and globally have been using FDD technology.[43] The 3G TD-SCDMA standard developed and adopted by China evolved into LTE-TDD.[44]

43. Each generational improvement in wireless technology engendered a revolution in applications and services that developed in response to the new capabilities created. For example, 2G technology introduced texting, which has become more ubiquitous than voice calls in the United States[45] and enabled basic data services.

44. 3G technology supported much higher data transmission rates than 2G technology. 3G ushered in the era of social media on wireless devices, such as Facebook and dating apps.[46] 3G also triggered the development of wireless applications such as location-based services,

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[39] *Grigorik 2013*.

[40] *Grigorik 2013*.

[41] For a period of time, Sprint attempted to develop and deploy another 4G technology called WiMAX, but this technology ultimately did not succeed, and Sprint pivoted to LTE. Brad Reed, "LTE vs. WiMAX," November 2, 2011, Network World, at https://www.networkworld.com/article/2182390/lte-vs--wimax.html.

[42] "LTE FDD, TDD, TD-LTE Duplex Schemes," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/4g-lte-long-term-evolution/tdd-fdd-td-lte-duplex-schemes.php.

[43] "LTE FDD, TDD, TD-LTE Duplex Schemes," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/4g-lte-long-term-evolution/tdd-fdd-td-lte-duplex-schemes.php; "GSA confirms 521 LTE networks launched, LTE-Advanced now mainstream," Global mobile Supplier Association, August 12, 2016, at https://gsacom.com/press-release/gsa-confirms-521-lte-networks-launched-lte-advanced-now-mainstream/.

[44] "What is 3G TD-SCDMA," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/3g-umts/td-scdma.php.

[45] "Corilyn Shropshire, "Americans prefer texting to talking, report says," *Chicago Tribune*, March 26, 2015, at https://www.chicagotribune.com/business/ct-americans-texting-00327-biz-20150326-story.html.

[46] Facebook's mobile site was launched in 2007, and its app was launched in 2010. See Taylor Casti, "The Evolution of Facebook Mobile," *Mashable*, August 1, 2013, at https://mashable.com/2013/08/01/facebook-mobile-evolution/. The first online dating apps appeared around 2007. Isabel Thottam, "The history of online dating," *eHarmony*, at https://www.eharmony.com/history-of-online-dating/.

instant messaging, video telephony, multimedia gaming, and live-video buffering, among others.[47]

45. LTE drives the most advanced generally available networks in the United States today.[48] LTE was the first digital wireless technology for which the United States had a leadership position in deployment,[49] and the advent of LTE technology has transformed the U.S. economy and the lives of its citizens. Many of the developments of the 3G era—video conferencing, mobile gaming, and other mobile applications—became viable because of the improved speeds and lower latencies of LTE networks.[50] LTE has allowed consumers to quickly and easily use the internet on their mobile devices, so that many of our daily activities, from booking airline tickets to ordering dinner, are now performed through mobile apps.

46. LTE has also transformed the way we acquire and listen to music (and transformed the music industry as a result)[51] and vastly improved the experience of streaming video to our mobile devices, thus transforming the market for pay television and creating new business models for video content.[52] The ability to stream video reliably has transformed police work[53] and healthcare.[54] It also enabled the creation of entirely new industries that have changed the way we live, such as ride-sharing, home-sharing, shopping and payment by

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[47] Prasant Kumar Pattnaik and Rajib Mall, FUNDAMENTALS OF MOBILE COMPUTING (PHI Learning Pvt. Ltd., 2015), p. 36.

[48] "LTE Achieves 4 Billion Connections Worldwide at end of 2018 — 47% of all Cellular Connections," 5G Americas, March 20, 2019, at https://www.globenewswire.com/news-release/2019/03/20/1758189/0/en/LTE-Achieves-4-Billion-Connections-Worldwide-at-end-of-2018-47-of-all-Cellular-Connections.html.

[49] Recon Analytics Report 2018, pp. 6-7.

[50] Vora 2015, p. 283-284; *Grigorik 2013*.

[51] Zachary Evans, "How Social Media and Mobile Technology Has Changed Music Forever," August 24, 2015, Social Media Week, at https://socialmediaweek.org/blog/2015/08/social-mobile-changed-music/.

[52] Services that were not supported by the previous technology generations have become possible in 4G. These include high-definition mobile TV, video conferencing, and 3D television. See Prasant Kumar Pattnaik and Rajib Mall, FUNDAMENTALS OF MOBILE COMPUTING (PHI Learning Pvt. Ltd., 2015), p. 37.

[53] "Eyes on the Street: How Wireless Video Solutions Are Transforming Public Safety," Motorola White Paper, 2012, at https://www.naco.org/sites/default/files/documents/Video%20Solutions%20Transforms%20Public%20Safety.pdf.

[54] Daniel Newman, "Top Five Digital Transformation Trends in Heath Care," Forbes, May 7, 2017, at https://www.forbes.com/sites/danielnewman/2017/03/07/top-five-digital-transformation-trends-in-healthcare/#4184fa4b2561.

phone, and gaming on phones.[55] The ease of shopping and logistics have empowered companies such as Amazon to transform the retail economy and the way consumers purchase products from appliances to shampoo.[56]

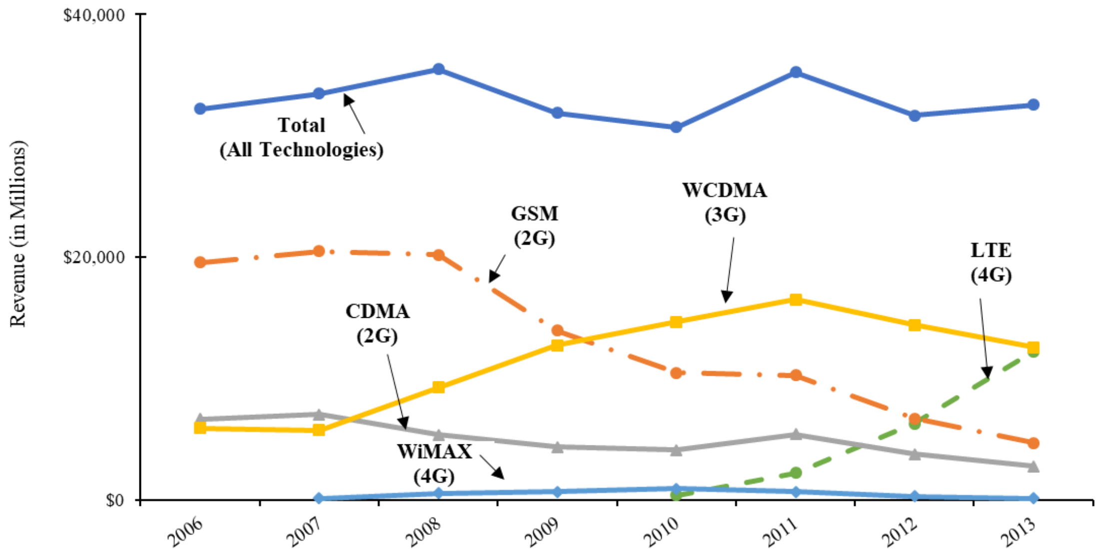
47. The timing of the rise and decline of each technology generation can be seen in the total worldwide RAN expenditures by carriers over time. Figure IV.1 shows the evolution of wireless RAN spending by technology from 2006 through 2013.[57] Since 2013, LTE RAN spending has significantly outpaced WCDMA spending and constituted the majority of RAN spending worldwide. 5G RAN sales started in Q4 2018 according to the data.

[55] Speaking at CTIA's 5G Summit, Sprint CEO Michel Combes claimed, "The U.S., and I know that from fact, was in Europe at that stage, was three years ahead of China and all the other countries in launching 4G. No one realized at that time, but it really gave U.S. businesses the opportunity to start an app revolution and now most of us can't imagine a world without apps like Uber, Facebook, and Instagram. Because of the high quality of American 4G networks and the hundreds of billions we invested, we have helped create the world's most valuable companies. In '16 alone, 4G contributed 100 billion dollars to the American economy, and it's fair to say that leadership in 4G to date has contributed more than a trillion dollars to the American economy." See, Michel Combes, Speech at CTIA's 5G Summit, April 4, 2019, at https://www.ctia.org/news/2019-5g-summit-event, at 07:29.

[56] Dennis Green, "Shopping changed a lot in 2017 – and smartphones are to blame," *Business Insider*, December 28, 2017, at https://www.businessinsider.com/mobile-shopping-exploded-this-year-2017-12.

[57] The data underlying Figure VI.1 were purchased under license from data vendor Dell'Oro Group. Here, and throughout this report, figures and analyses that rely on data from Dell'Oro Group have been purged of specific numbers and/or certain time periods per requirements of the data vendor.

Figure IV.1
Global Wireless Spending on Wireless RAN Equipment by Technology (in Millions), 2006-2013



Note: WiMAX data were not collected by Dell'Oro Group after 2015, because the revenues from WiMAX RAN equipment were very low.

Source: "TOTAL GSM," "TOTAL CDMA," "TOTAL WCDMA," "TOTAL LTE," "TOTAL 5G NR," Dell'Oro Group, Q1 2019.

48. 5G mobile technology is currently under development by 3GPP.[58] 3GPP is defining 5G standards in two releases: Release 15 and Release 16.[59] The first stage of Release 15, finalized by 3GPP in December 2017, defined the non-standalone ("NSA") 5G configuration, in which only the standards for 5G RAN, also known as 5G New Radio ("5G NR"),[60] were defined.[61] The second stage of Release 15 was finalized by 3GPP in June 2018, and it defined the standalone ("SA") 5G configuration, meaning that both the

[58] "3GPP Release 15 Overview." IEEE Spectrum, at https://spectrum.ieee.org/telecom/wireless/3gpp-release-15-overview.

[59] "3GPP Release 15 Overview." IEEE Spectrum, at https://spectrum.ieee.org/telecom/wireless/3gpp-release-15-overview.

[60] See "5G NR New Radio," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/5g-mobile-wireless-cellular/5g-nr-new-radio.php. When I refer to radio access network in this report, I refer to both hardware (i.e., sites, antennas, base stations, etc.) and software needed to operate the hardware.

[61] David Abecassis, Janette Stewart, Chris Nickerson, "Global Race to 5G – Update," Analysys Mason, April 2019 (hereafter, *2019 Global Race to 5G Analysys Mason Report*), p. 17.

5G RAN and core networks were defined.[62] In March 2020, 3GPP is scheduled to finalize Release 16, which would provide further standardization of the 5G technology and its applications.[63] 5G standards are still being developed. As with other wireless generations, there will be future releases defining evolving standards for 5G.[64]

49. The first 5G deployments in the United States are NSA 5G networks.[65] Because the NSA configuration focuses on augmenting the RAN equipment in the carriers' networks (as opposed to the core equipment), the availability and quality of 5G RAN equipment is of primary importance for the early deployment of 5G in the U.S.

50. The first commercial 5G networks that enabled Fixed Wireless Access ("FWA") for end-users (access to 5G services via "fixed" user equipment such as hotspots, as opposed to access via mobile handsets[66]) were launched in 2018 by carriers in the United States and South Korea.[67] In April 2019, carriers in the United States and South Korea were also the first to launch commercial services that enabled consumers to access 5G networks via mobile handsets.[68] In addition, analysts have identified 201 carriers in 83 countries that are actively investing in 5G by obtaining licenses to conduct trials, are conducting tests and trials, deploying networks, or some combination of these activities.[69]

51. Appendix D summarizes the rapidly changing status of 5G deployments and launches worldwide as of this writing. I will discuss in Section VI that, as of today, South Korea is

[62] "3GPP Release 15 Overview." *IEEE Spectrum*, at https://spectrum.ieee.org/telecom/wireless/3gpp-release-15-overview.

[63] "Release 16," *3GPP*, updated July 16, 2018, at https://www.3gpp.org/release-16.

[64] "Release 17," *3GPP*, at https://www.3gpp.org/release-17; "3GPP 3GPP Specification Release Numbers," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/3gpp/standards-releases.php.

[65] Irina Cotanis, "5 Critical 5G Network Deployment Challenges," Infovista Blog, August 15, 2019, at https://www.infovista.com/blog/5g-network-deployment-challenges?utm_source=facebook&utm_medium=update.

[66] "Fixed Wireless Access," Redline Communications, at https://rdlcom.com/fixed-wireless-access/.

[67] See Appendix D.

[68] See Appendix D.

[69] *2019 Global Race to 5G Analysys Mason Report*, p. 8.

well ahead of other countries, including the United States, in commercial deployment of 5G, reporting over one million subscribers.[70]

B. 5G Technology Will Enable Transformative Benefits and Uses

52. Just as the previous generational improvements in wireless technology instigated sea changes in the wireless ecosystem and in our lifestyles, 5G is likely to usher in new products, services, and ways of interacting with each other and the world that will change our lives and affect our economy.

53. 5G technology provides massive capacity, speed, and latency improvements over 4G. Given these technological improvements over 4G, there are four major applications currently anticipated for 5G.[71]

54. Latency refers to the delay between when a customer makes a request for data and when those data are returned.[72] Capacity is the amount of traffic that a network can handle at any given time, such as the number of simultaneous calls and maximum data speeds.[73]

55. First, because of its substantial capacity increases, 5G will alleviate some of the capacity constraints on existing 4G networks. The use of 5G for the enhancement of current mobile broadband services and applications is known as enhanced mobile broadband ("eMBB").[74]

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[70] Jeremy Horwitz, "South Korea hits 1 million 5G subscribers in 69 days, beating 4G record," *Venture Beat*, June 12, 2019, at https://venturebeat.com/2019/06/12/south-korea-hits-1-million-5g-subscribers-in-69-days-beating-4g-record/.

[71] The set of objectives for the first three use cases—eMBB, massive machine type communications, and ultra-reliable and low latency communications—known as International Mobile Telecommunications for 2020 ("IMT-2020") were developed by the International Telecommunications Union ("ITU"), which is a specialized agency of the United Nations that focuses on the global allocation of spectrum. See "About International Telecommunications Union (ITU)," *ITU*, at https://www.itu.int/en/about/Pages/default.aspx; "IMT Vision—Framework and overall objectives of the future development of IMT for 2020 and beyond," Recommendation ITU-R M.2083-0, September 2015 (hereafter, *IMT-2020 Recommendation*), pp. 1 and 11-12. Fixed wireless access is often referenced in the literature as a fourth use case, as discussed below. See Kai Korschelt *et al.*, "Entering the 5G cycle," *Canaccord Genuity Global Equity Research*, October 1, 2018 (hereafter, *Korschelt et al.-Cannacord 10/1/2018*), p. 6.

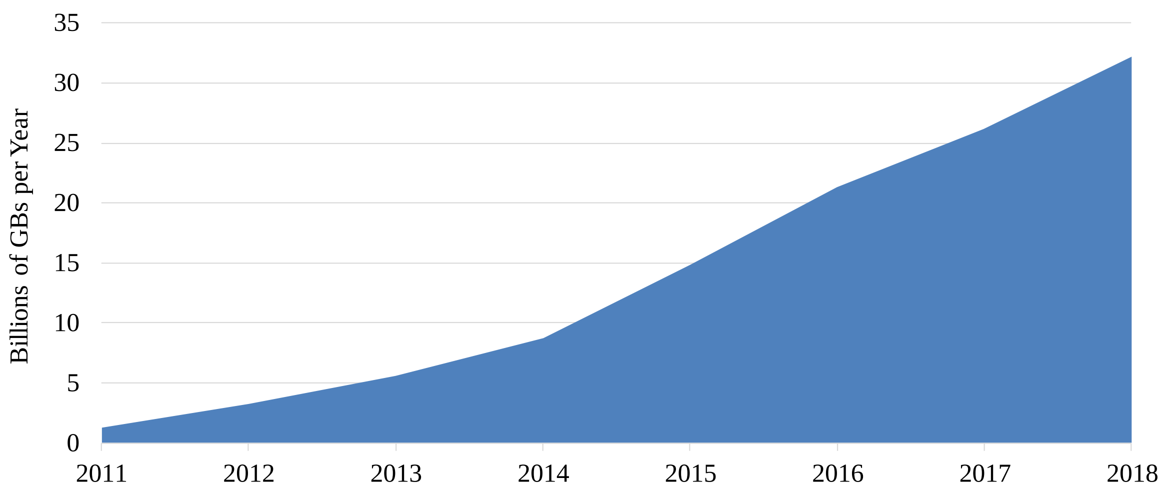
[72] See "Understanding mobile network experience: What do Opensignal's metrics mean?" *Opensignal Insights*, at https://www.opensignal.com/blog/2019/01/03/understanding-mobile-network-experience-what-do-opensignals-metrics-mean.

[73] See "Network capacity – definition," *GSMArena*, at https://www.gsmarena.com/glossary.php3?term=network-capacity.

[74] *IMT-2020 Recommendation*, p. 11.

56. Mobile data traffic in North America has increased by approximately 58 percent every year from 2011 to 2018.[75] Figure IV.2 shows the rapid rise of mobile traffic in the North America in just this decade. As data traffic increases, carriers must continually increase the capacity in their wireless networks if they are to handle the increased data load at acceptable quality levels. They can increase the capacity of their networks by increasing the number of cell sites and/or by increasing the capacity of the existing cell sites. McKinsey & Company projects that without purchasing new spectrum or increasing the number of cell sites, at least one carrier in the United States would run out of capacity on at least 50 percent of its cell sites by 2020.[76]

Figure IV.2
Mobile Data Traffic - North America, 2011-2018



Source: "Mobile data traffic," *Ericsson Mobility Visualizer*, at https://www.ericsson.com/en/mobility-report/mobility-visualizer?f=7&ft=2&r=4&t=8&s=4&u=3&y=2011,2018&c=3.

57. The 5G enhancement, eMBB, will support 100 times more traffic than does 4G technology and will increase peak speeds from 1 gigabit per second ("Gbps") to 20 Gbps.[77] Capacity

[75] "Mobile data traffic," Ericsson Mobility Visualizer, at https://www.ericsson.com/en/mobility-report/mobility-visualizer?f=7&ft=2&r=1&t=1,20&s=4&u=3&y=2011,2024&c=3.

[76] Ferry Grijpink *et al.*, "The road to 5G: The inevitable growth of infrastructure cost," *McKinsey & Company*, February 2018, at https://www.mckinsey.com/industries/telecommunications/our-insights/the-road-to-5g-the-inevitable-growth-of-infrastructure-cost.

[77] *IMT-2020 Recommendation*, pp. 11, 13-14.

improvements will enable the network to carry massive numbers of connections simultaneously[78] and will also help support ever-increasing data usage. 5G is also predicted to lower the cost per gigabyte ("GB") of data substantially.[79]

58. In addition, 5G will allow devices to communicate in almost real time, with latency as low as one tenth that of 4G.[80]

59. Higher speeds and lower latency will improve customers' experiences with current applications and uses, such as watching videos, surfing the internet, and engaging with social media. Higher speeds and lower latency will also undoubtedly engender newer technologies like augmented and virtual reality, 8K (ultra-high definition) video, new forms of social media,[81] and other applications and technologies that are not yet anticipated.

60. The second application of 5G is massive machine type communications ("mMTC"). This is a category of services for vast numbers of IoT devices that do not require high speeds but do require high connection density.[82] mMTC will support at least one million devices for every square kilometer.[83] Examples of mMTC devices include actuators, remote sensors, and equipment monitors.[84] Municipalities can use these mMTC devices to monitor a variety of factors, from trash levels to the flow of traffic on a street. The data can be used to save energy on lighting empty streets or on routing public transit.[85]

61. Another highly anticipated benefit of mMTC is energy efficiency gained through "smart grids."[86] Smart grids can measure real-time power demands instead of relying on

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[78] Mark Collins *et al.*, "Are you ready for 5G?" February 2018, *McKinsey & Company*, at https://www.mckinsey.com/industries/telecommunications/our-insights/are-you-ready-for-5g.

[79] "The 5G Consumer Business Case. An economic study of enhanced mobile broadband," *Ericsson*, 2018, pp. 2, 7, at https://www.ericsson.com/assets/local/networks/documents/the-5g-consumer-business-case.pdf.

[80] *IMT-2020 Recommendation*, pp. 14-15.

[81] "5G Top 10 Use Cases," *Huawei Technologies Inc.*, at https://www.huawei.com/us/industry-insights/outlook/mobile-broadband/xlabs/use-cases/5g-top-10-use-case; Geoffrey Morrison, "TV resolution confusion: 1080p, 2K, UHD, 4K, 8K, and what they all mean," *CNET*, February 7, 2019, at https://www.cnet.com/news/4k-1080p-2k-uhd-8k-tv-resolutions-explained/.

[82] *IMT-2020 Recommendation*, pp. 12, 15.

[83] *IMT-2020 Recommendation*, p. 14.

[84] *Dahlman et al. 2018*, p. 4.

[85] "5G in 360," *CTIA*, at https://www.ctia5gin360.org/360/.

[86] "5G and Energy," 5G-Infrastructure-Association, September 30, 2015, pp. 3, 12, and 36.

inefficient predictive models and are expected to lead to "improved power quality, fewer power outages, smaller power outage areas, and easier grid deployments with less environmental impact in urban areas."[87] Analysts estimate that smart grids could generate $1.8 trillion in efficiency savings, thus saving consumers hundreds of dollars every year.[88]

62. In the healthcare sector, it is expected that mMTC will be used to monitor chronic illnesses and communicate with patients remotely. Goldman Sachs estimates that mMTC could save the United States $305 billion a year by curbing preventable healthcare costs.[89]

63. The third category of 5G applications is known as ultra-reliable and low latency communications ("URLLC").[90] Services that require low latency and high reliability include traffic safety, self-driving cars, and factory automation.[91] Deloitte, a global professional services firm, estimates that self-driving cars could reduce pollution emissions by 40-90 percent, reduce the average cost per passenger mile by 70 percent, and save 100 billion hours of productivity currently lost to driving.[92] A study by the Eno Center for Transportation predicts that if 90 percent of the vehicles in the United States were self-driving, 21.7 thousand lives and 447.1 billion dollars would be saved annually in the United States.[93]

64. A fourth category of 5G use is FWA, which will allow provision of "last mile" high-speed broadband service to residential and business customers over the wireless network. FWA is considered a more cost-effective alternative to fixed broadband provision in many areas.[94] "Last mile" deployment of wireline broadband (i.e., the wireline connections from neighbourhood or regional network nodes to customers' homes or offices) can be

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[87] "5G and Energy," 5G-Infrastructure-Association, September 30, 2015, pp. 15 and 17.

[88] "Industry Data," *CTIA*, at https://www.ctia.org/the-wireless-industry/infographics-library?topic=17.

[89] David H. Roman and Kyle D. Conlee, "The Digital Revolution comes to US Healthcare: Technology, incentives align to shake up the status quo," *Goldman Sachs Global Investment Research*, June 29, 2015, pp, 4, 7.

[90] *IMT-2020 Recommendation*, pp. 11-12.

[91] *IMT-2020 Recommendation*, pp. 11-12.

[92] Scott Corwin *et al.*, "The future of mobility: How transportation technology and social trends are creating a new business ecosystem," *Deloitte University Press*, 2017, pp. 6, 19.

[93] "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations," *Eno Center for Transportation*, October 2013, p. 8.

[94] *Korschelt et al.-Cannacord 10/1/2018*, p. 6.

prohibitively expensive, especially in rural areas. Compared to wireline alternatives such as fiber-to-the-home ("FTTH"), FWA has significantly lower capital expenditures, can be deployed quickly, and has lower operating expenditures.[95]

65. Globally, initial 5G applications are anticipated to be eMBB and FWA. mMTC and URLLC are anticipated to gain scale at a later stage.[96] However, as noted earlier, initial 5G applications in the United States are predominantly FWA and not eMBB.[97] I discuss the reason that U.S. deployment is following a different path from the rest of the world in the next section.

V. THE SPECTRUM "GAP" IN THE UNITED STATES

A. U.S. Policy Regarding 5G Deployment

66. The FCC declared the importance of broadband infrastructure in its 2010 National Broadband Plan:

> Like electricity a century ago, broadband is a foundation for economic growth, job creation, global competitiveness and a better way of life. It is enabling entire new industries and unlocking vast new possibilities for existing ones. It is changing how we educate children, deliver health care, manage energy, ensure public safety, engage government, and access, organize and disseminate knowledge.[98]

67. Ajit Pai, the current Chairman of the FCC, identified wireless innovation, and ensuring the U.S. leadership in it, as one of the agency's top priorities.[99]

68. Indeed, the FCC considers it important that the United States "win the race" to implement 5G:

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[95] Korschelt et al.-Cannacord 10/1/2018, p. 6.

[96] "The promise and potential of 5G: Evolution or revolution?" IHS Markit, 2019, p. 7; 2019 Global Race to 5G Analysys Mason Report, p. 3.

[97] 2019 Global Race to 5G Analysys Mason Report, p. 3.

[98] "Connecting America: The National Broadband Plan," The Federal Communications Commission, March 17, 2010, p. XI.

[99] See Ajit Pai's video speech at "The FCC's 5G FAST Plan," FCC, at https://www.fcc.gov/5G.

> America is in the midst of a transition to the next generation of wireless services, known as 5G. These new services can unleash a new wave of entrepreneurship, innovation, and economic opportunity for communities across the country. The FCC is committed to doing our part to help ensure the United States wins the global race to 5G to the benefit of all Americans.[100]

69. However, the United States is not the only country that aspires to be a leader in 5G. Countries and carriers are competing vigorously to be the first to offer commercial 5G networks. Analysys Mason, a consulting and research company specializing in telecommunications, media, and technology,[101] anticipates that around 80 operators in more than 40 countries will make 5G services available to their subscribers by 2020.[102]

B. The State of 5G Deployment in the United States and the Rest of the World

i. Key Spectrum Bands Are Currently Unavailable to Carriers in the United States

70. The United States faces challenges to timely 5G deployment that other countries do not face. Specifically, the United States currently lacks available spectrum suitable for broad deployment of 5G, because the relevant spectrum has already been allocated by the FCC for other uses.[103]

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[100] Declaratory Ruling and Third Report and Order, In the Matter of Accelerating Wireless Broadband Deployment by Removing Barriers to Infrastructure Investment; and Accelerating Wireline Broadband Deployment by Removing Barriers to Infrastructure Investment, Before the Federal Communications Commission, WT Docket No. 17-79; and WC Docket No. 17-84, FCC 18-133 (Released: September 27, 2018), ¶ 1.

[101] "About Us," Analysys Mason, at http://www.analysysmason.com/About-Us/Who-we-are/.

[102] 2019 Global Race to 5G Analysys Mason Report, p. 1.

[103] "FCC Online Table of Frequency Allocations," 47 C.F.R. § 2.106, Federal Communications Commission, Office of Engineering and Technology, Policy and Rules Division, revised on May 7, 2019, at https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

71. As with any wireless service, spectrum is essential for 5G deployment.[104] To deploy commercial mobile 5G networks on a nationwide and, ultimately, ubiquitous basis, it is generally understood that carriers need low-, mid-, and high-band spectrum.[105]

72. Due to its physical properties, low-band spectrum—frequencies below 3 GHz[106]—can travel long distances and reach indoors. Low-band spectrum is currently considered necessary to economically provide 5G coverage in suburban and rural areas.[107] However, low-band spectrum does not offer the same high speeds that can be achieved with 5G deployment in mid-band and high-band spectrum for two reasons. First, the speed available in 5G depends on the width of the available spectrum, and available bandwidths in low-band spectrum are relatively narrow.[108] Second, massive MIMO technology, a key component of 5G that drives its speed and efficiency (discussed at length in Section VII.C

[104] Spectrum is a necessary input into wireless service. Wireless voice and data services are provided "through the air" via the electromagnetic spectrum, from a user's wireless device to a nearby communications tower and vice versa. Radio spectrum is a range of the electromagnetic spectrum. Radio spectrum at frequencies from 3 kilohertz ("kHz") to 300 gigahertz ("GHz") is used to transmit sound, data, and video. Radio spectrum allows the transmission of voice communications to and from cell phones, television signals from broadcasters' antennas to consumers' televisions, radio signals from radio broadcast antennas to consumers' AM and FM radios, and data communications such as internet web sites, music, photos, and video to and from smartphones. U.S. Government Accountability Office, "Internet of Things: FCC Should Track Growth to Ensure Sufficient Spectrum Remains Available," GAO-18-71, November 2017, footnote 1, p. 1 and note to Figure 2, p. 8; Marguerite Reardon, "Wireless spectrum: What it is, and why you should care," CNET, August 13, 2012, at https://www.cnet.com/news/wireless-spectrum-what-it-is-and-why-you-should-care/; and Mike Freeman, "Too much mobile data, not enough airwaves," *The San Diego Union-Tribune*, August 11, 2013, at http://www.sandiegouniontribune.com/business/technology/sdut-Spectrum-Qualcomm-mobile-data-smartphones-tablets-2013aug11-htmlstory.html.

[105] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, p. 2.

[106] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, p. 2.

[107] "A National Spectrum Strategy to Lead in 5G," *CTIA*, pp. 5-6.

[108] "Professor Rappaport Explains Why T-Mobile 5G 600 MHz Ultimately Doesn't Make It," Wireless One, May 3, 2018, at http://wirelessone.news/10-r/1037-professor-rappaport-explains-why-t-mobile-5g-600-mhz-are-a-dud. Theodore Rappaport serves as the David Lee/Ernst Weber Professor of Electrical Engineering at New York University's ("NYU") Tandon School of Engineering, a professor of computer science at the NYU Courant Institute of Mathematical Sciences, and a professor of radiology at the NYU School of Medicine. See "Faculty: Theodore Rappaport," NYU Tandon School of Engineering, Polytechnic Institute, at https://engineering.nyu.edu/faculty/theodore-rappaport. "5G Spectrum Vision," 5G Americas Whitepaper, p. 17, at http://www.5gamericas.org/files/4015/4958/3330/5G_Americas_5G_Spectrum_Vision_Whitepaper.pdf; Berge Ayvazian, Fred Campbell, and Haig Sarkissian, "Spectrum Strategies for 5G: 2019 Update." Wireless 20|20, January 2019, p. 5, at http://www.wireless2020.com/media/white-papers/Spectrum-Strategies-for-5G-2019-Update.pdf.

below), is not currently feasible in low-band spectrum because the long wavelengths of low-band spectrum require antennas that are too large to fit into massive MIMO arrays.[109]

73. High-band spectrum—spectrum at frequencies above 24 GHz,[110] also known as millimeter wave ("mmW") spectrum—is important for high-speed and high-capacity applications. High-band spectrum waves, however, have poor propagation characteristics relative to lower frequency bands with respect to distance and ability to penetrate obstacles.[111] Hence, it is generally considered uneconomic to deploy 5G using mmW spectrum for mobile applications in any but the most densely populated areas, such as central metro areas, transportation centers (e.g., airports), and event locations (e.g., stadiums).[112] Even in these densely populated areas, 5G deployed in mmW spectrum is not projected to cover entire large central metro areas. Instead, it is projected to be selectively deployed in densely populated areas to provide adequate data capacity.[113]

74. Mid-band spectrum (spectrum at frequencies between 3 and 24 GHz[114]) is called a "key building block" for 5G.[115] Its physical properties provide mid-band spectrum with good coverage and high capacity, making it the most suitable spectrum band for economic deployment of 5G in urban areas.[116] Countries such as Japan, South Korea, Spain, China,

[109] "Professor Rappaport Explains Why T-Mobile 5G 600 MHz Ultimately Doesn't Make It," Wireless One, May 3, 2018, at http://wirelessone.news/10-r/1037-professor-rappaport-explains-why-t-mobile-5g-600-mhz-are-a-dud.

[110] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, p. 2.

[111] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, p. 2.

[112] David Sosa and Greg Rafert, "The Economic Impacts of Reallocating High-Band Spectrum to 5G in the United States," *Analysis Group*, April 2019, pp. 2, 11-12.

[113] David Sosa and Greg Rafert, "The Economic Impacts of Reallocating High-Band Spectrum to 5G in the United States," *Analysis Group*, April 2019, pp. 11-12.

[114] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, p. 2.

[115] "A National Spectrum Strategy to Lead in 5G," *CTIA*, p. 6.

[116] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, p. 2.

Switzerland, and the United Kingdom have been focusing on mid-band spectrum for 5G deployment.[117]

75. According to Analysys Mason, mid-band spectrum is essential for the U.S. 5G commercial launch:

> Many of the planned 5G commercial launches referred to in our report will use mid-band spectrum…The US has previously lagged behind other nations in terms of the amount of mid-band spectrum being released for 5G use. Whilst there has been significant progress in the US on other important aspects of 5G launch, such as reform of infrastructure planning procedures (e.g. in relation to small-cell siting), there is still more to be done to ensure that the US retains its leading position through better availability of mid-band spectrum, which is a key short-term goal.[118]

76. Data on sales of RAN equipment show that 5G RAN equipment for sub-6 GHz technology (i.e., technology that operates in low- and mid-spectrum bands between 450 MHz and 6 GHz[119]) accounted for approximately 95 percent of total 5G RAN sales in Q4 2018-Q1 2019 worldwide.[120] Revenue from mmW (i.e., 5G RAN that operates in high-band spectrum bands between 24.25 GHz and 52.60 GHz[121]) technology equipment was much smaller—approximately 5 percent of total global 5G RAN equipment revenues. These data also confirm that only a small fraction of deployments use equipment operating in high-band spectrum.

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[117] "A National Spectrum Strategy to Lead in 5G," *CTIA*, p. 6; Anne Morris, "Swisscom Readies for Europe's First Commercial 5G Launch With Phones," *SDX Central*, April 10, 2019, at https://www.sdxcentral.com/articles/news/swisscom-readies-for-europes-first-commercial-5g-launch-with-phones/2019/04/; "MIIT awards 5G licences to three MNOs plus cable operator," *TeleGeography*, June 6, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/06/06/miit-awards-5g-licences-to-three-mnos-plus-cable-operator/index.html.

[118] *2019 Global Race to 5G Analysys Mason Report*, p. 2.

[119] See 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Release 15 Description; Summary of Rel-15 Work Items (Release 15), TR 21.915 v1.0.0 (2019-03), p. 29.

[120] See "MOBILE RADIO ACCESS NETWORK – 5G NR – Sub 6 GHz" and "TOTAL 5G NR," Dell'Oro Group, Q1 2019.

[121] See 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Release 15 Description; Summary of Rel-15 Work Items (Release 15), TR 21.915 v1.0.0 (2019-03), p. 29.

77. FCC Chairman Ajit Pai called mid-band spectrum "important" for deployment of 5G in the United States.[122] The FCC identified three mid-bands for 5G networks buildout: 3.5 GHz, 3.7-4.2 GHz, and 2.5 GHz bands.[123] The U.S. Department of Commerce's National Telecommunications and Information Administration ("NTIA") additionally identified the 3.45-3.55 GHz band as a band that could potentially be repurposed for commercial wireless use.[124]

78. The United States is unique in spectrum allocation. In the United States, low- and high-band spectrum has been allocated for mobile use, but other than the mid-band spectrum in 2.5 GHz bands available to only Sprint, [125] mid-band spectrum has not been made available for mobile use.[126] As of June 2019, the 3.45-3.55 GHz, 3.5 GHz, and 3.7-4.2 GHz bands were unavailable to U.S. carriers, and the auctions of these spectrum bands had yet to be

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[122] Statement of Chairman Ajit Pai, Federal Communications Commission, Hearing on "Oversight of the Federal Communications Commission," Before the United States Senate Committee on Commerce, Science, and Transportation, June 12, 2019, available at https://docs.fcc.gov/public/attachments/DOC-357959A1.pdf.

[123] Note that while many sources categorize 2.5 GHz band as a low-band, the FCC categorizes it as a mid-band. See "The FCC's 5G FAST Plan," *FCC*, at https://www.fcc.gov/5G; *2019 Global Race to 5G Analysys Mason Report*, p. 23. Similar to the FCC, I refer to 2.5 GHz bands as a mid-band in this report.

[124] "5G Spectrum Vision," *5G Americas Whitepaper*, February 2019, p. 7.

[125] "Sprint Lights Up True Mobile 5G in Atlanta, Dallas-Fort Worth, Houston and Kansas City," Sprint Press Release, May 30, 2019, at https://newsroom.sprint.com/sprint-lights-up-true-mobile-5g-in-atlanta-dallas-fort-worth-houston-and-kansas-city.htm.

[126] *2019 Global Race to 5G Analysys Mason Report*, Figures 4.1, 4.4, and 4.7.

scheduled.[127] Sprint, moreover, does not have sufficient low- or any high-band spectrum necessary for nationwide 5G deployment.[128,129]

79. The United States is therefore at a material disadvantage in competing for leadership in 5G deployment with countries in which mid-band spectrum has already been allocated (e.g., China, Japan, and South Korea[130]), while in the United States mid-band spectrum is unavailable to three of the four top carriers and no clear timeline for its allocation has been established. I refer to this situation as the U.S. "spectrum gap."

ii. The United States Is Currently Well Behind Other Countries in 5G Deployments

80. Despite the lack of adequate mid-band spectrum in the United States, all four major U.S. carriers have announced plans for 5G deployment. All four carriers had launched commercial 5G networks at the time of this report.[131]

81. Verizon, T-Mobile, and AT&T have launched their networks in mmW spectrum (28 GHz and 39 GHz); Sprint is using its 2.5 GHz mid-band spectrum for its 5G network.[132]

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[127] 2019 Global Race to 5G Analysys Mason Report, Figure 4.5.

[128] Sprint does not have low-band spectrum available for 5G deployment. See John Saw, "Winning the Global Race to 5G," Sprint, April 4, 2019 at https://newsroom.sprint.com/winning-global-race-to-5g.htm. Sprint does not own licenses for high-band spectrum. See Mike Dano, "Special Report – 25 charts on spectrum ownership in the United States," FierceWireless, July 12, 2018, at https://www.fiercewireless.com/wireless/25-charts-spectrum-ownership-united-states; Joan Engebretson, "5G Millimeter Wave Auction Winners: AT&T, T-Mobile, Verizon, Windstream, Starry, and Others," Telecompetitor, June 3, 2019, at https://www.telecompetitor.com/5g-millimeter-wave-auction-winners-att-t-mobile-verizon-windstream-starry-and-others/.

[129] A merger between Sprint and T-Mobile was approved on June 26, 2019 by the U.S. Department of Justice. When Sprint and T-Mobile merge, the merged company will combine low- and high-band spectrum owned by T-Mobile with mid-band spectrum owned by Sprint to become the only U.S. carrier with all three spectrum bands necessary for nationwide 5G deployment. Sprint and T-Mobile project that the combination of T-Mobile's low- and high-band spectrum and Sprint's mid-band spectrum will deliver over 400 MHz of spectrum, improving the capacity that standalone Sprint and T-Mobile offer today, combined, by a factor of eight. See, "T-Mobile and Sprint Receive Clearance from Department of Justice for Merger to Create the New T-Mobile," T-Mobile Press Release, June 26, 2019, at https://investor.t-mobile.com/news-and-events/t-mobile-us-press-releases/press-release-details/2019/T-Mobile-and-Sprint-Receive-Clearance-from-Department-of-Justice-for-Merger-to-Create-the-New-T-Mobile/default.aspx; "Leading the 5G For All Revolution," T-Mobile and Sprint, at https://newtmobile.com/leading-the-5g-revolution/.

[130] 2019 Global Race to 5G Analysys Mason Report, Figure 4.4.

[131] See Appendix D.

[132] See Appendix D.

82. Nevertheless, data show that despite the efforts of the U.S. carriers to deploy in available spectrum bands, the United States is well behind Asia in 5G deployment.

83. Dell'Oro data indicate that the highest spending on 5G RAN in Q4 2018-Q1 2019, the first two quarters that record data on 5G RAN spending, occurred in North America and Asia Pacific. The majority of all global spending on 5G RAN equipment in these two quarters was in Asia, which exceeded spending on 5G RAN equipment in North America by a factor of three.

84. As detailed in Appendix D, carriers in other counties have launched commercial 5G networks using mid-band spectrum. These include Sunrise and Swisscom in Switzerland and SK Telecom, KT, and LG Uplus in South Korea.[133]

85. Japan, China, and the UAE have not yet launched commercial 5G services but have made significant progress in 5G deployment.[134] While China has not yet launched a commercial 5G network, some analyst reports identify China as a leader in the "race" to 5G implementation. China's record of rapid network deployment, committed funds to 5G-related investment, strong government and industry backing, extensive testing, and availability of large amounts of mid-band spectrum contribute to China's leading position.[135] Chinese carriers were granted 5G spectrum licenses a year ahead of China's initial schedule, accelerating 5G network rollouts.[136]

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[133] See Appendix D.

[134] See Appendix D.

[135] Deloitte highlighted China's rapid network densification since 2015, which is important for 5G, and China's five-year economic plan that allocates $400 billion for 5G-related investment. Based on these two criteria, Deloitte identified China as one of the leaders in 5G race. Dan Littman *et al.*, "5G: The chance to lead for a decade," *Deloitte*, 2018, pp. 1, 4-5. Analysys Mason found that China and the United States were leaders in terms of 5G readiness in spring of 2019. The earliest 5G rollout in China is projected to start in Q4 2019. See *2019 Global Race to 5G Analysys Mason Report*, pp. 1, 25-26, 56, 64, and 66; Appendix D.

[136] Mike Dano, "China Finally Lights Its 5G Fire," *Light Reading*, June 6, 2019, at https://www.lightreading.com/mobile/5g/china-finally-lights-its-5g-fire/d/d-id/752001.

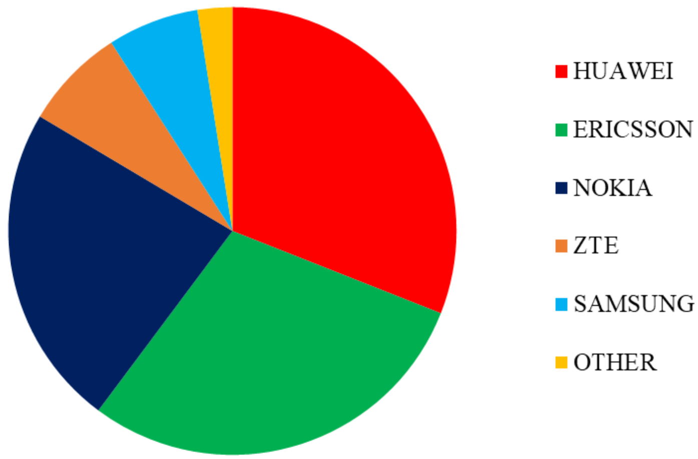
VI. THE MARKET FOR RAN NETWORK EQUIPMENT IN THE UNITED STATES AND THE REST OF THE WORLD

86. The development and manufacture of RAN equipment for new technologies is highly complex, requiring substantial R&D investment, expertise, and experience. There are only five companies in the world that have the capabilities to participate meaningfully in the RAN market. They are Huawei, Telefonaktiebolaget LM Ericsson ("Ericsson"), Nokia Corporation ("Nokia"), Samsung Electronics Co., Ltd. ("Samsung"), and ZTE Corporation ("ZTE").[137] Profiles of the five major RAN equipment vendors are provided in Appendix A.

87. Huawei is the leading provider of RAN equipment worldwide. Figure VI.1 shows vendor revenue shares of RAN equipment for all technologies in 2018. As the figure shows, approximately one-third of all RAN equipment spending worldwide was on Huawei equipment. Huawei had the largest revenue share in the market for RAN equipment worldwide in 2018.

[137] Other significant competitors that existed in the last decade include Nortel Networks (whose wireless technologies unit was auctioned to Ericsson in bankruptcy proceedings in 2009), Motorola Solutions (the majority of whose wireless network infrastructure assets were acquired by Nokia in April 2011), and Alcatel-Lucent (which was acquired by Nokia in January 2016). See Ian Austen, "Ericsson Wins Auction for Nortel Assets," *The New York Times*, July 26, 2009, at https://www.nytimes.com/2009/07/27/technology/companies/27iht-nortel.html; Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2012, p. 48; Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2014, p. 5.

Figure VI.1
Revenue Shares of RAN Equipment Vendors - Worldwide, 2018



Note: These data include sales of GSM, CDMA, WCDMA, LTE, and 5G RAN equipment.

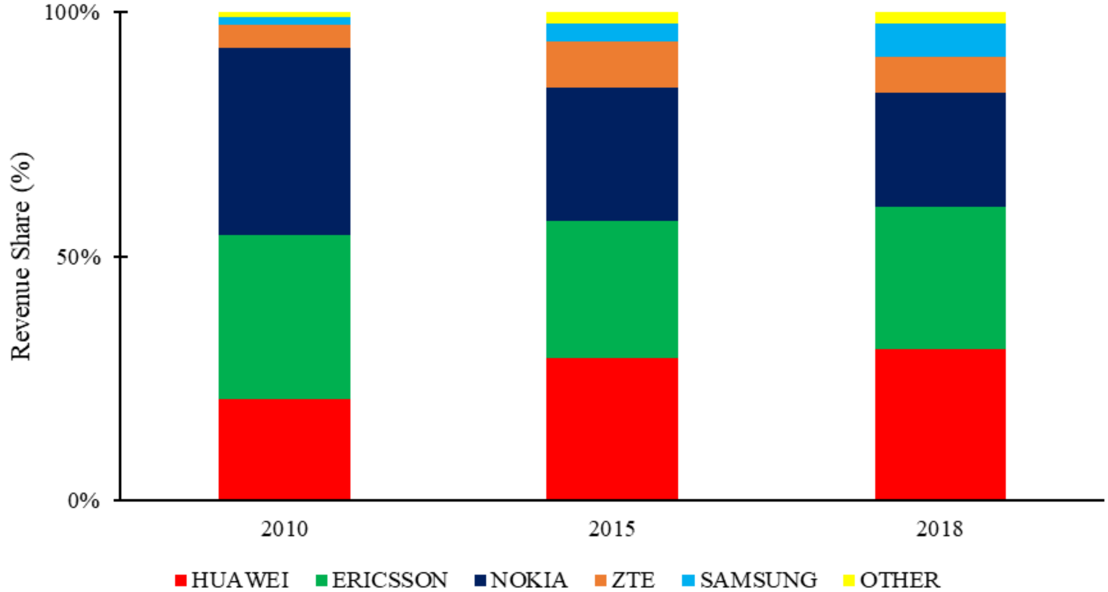
Source: "TOTAL MOBILE RADIO ACCESS NETWORK (GSM+CDMA+WCDMA+WiMAX+LTE+5G NR)," Dell'Oro Group, Q1 2019.

88. Figure VI.1 also shows that Ericsson and Nokia capture the majority of sales outside of Huawei, and Samsung and ZTE also have material, although smaller, volumes of sales of RAN equipment.

89. Figure VI.2 shows the revenue shares of the top five providers of RAN equipment worldwide for each year in 2010, 2015, and 2018. Huawei has been the leading provider of RAN equipment globally since 2015, despite the fact that Huawei has never had a material presence in the U.S. market.[138] The figure and data also show that Nokia's aggregated RAN sales share worldwide has been declining in recent years and Ericsson's aggregated RAN sales share has been approximately flat in recent years, while the revenue shares of Huawei and Samsung have been increasing. The revenue share of ZTE increased from 2013 through 2016, but it has been declining over the last two years.

[138] Huawei's revenue share in the North American region, which includes the United States and Canada, has been consistently low over this period.

Figure VI.2
Revenue Shares of Top 5 RAN Equipment Vendors – Worldwide, 2010, 2015, and 2018



Note: Nokia acquired the wireless networks business of Panasonic Systems Networks Company Limited in January 2015, and Alcatel-Lucent in January 2016. I include all three companies' revenues in the calculation of Nokia's revenue shares.

Source:
[1] TOTAL MOBILE RADIO ACCESS NETWORK (GSM+CDMA+WCDMA+WiMAX+LTE+5G NR)," Dell'Oro Group, Q1 2019.
[2] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2014, p. 5.
[3] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2016, p. 2.

90. Huawei's global leadership in RAN equipment spans the most advanced countries and less developed countries. Huawei had the highest revenue share of RAN equipment in Europe, Asia Pacific, and the Middle East and Africa in 2018, and had the second-largest revenue share in the Caribbean and Latin America ("CALA"). The broad acceptance and use of Huawei's RAN equipment evidences the respect for Huawei's technology throughout the world.

91. Huawei reported to the FCC that its multinational operations support more than 500 major telecommunications operators across more than 170 countries. It also reported that in mid-

2018 it served 45 out of world's 50 largest telecommunications providers.[139] As of 2016, Huawei supplied more than half of the 537 4G networks globally and 59 of the 90 4.5G networks[140] globally.[141]

92. Clearly, carriers around the world, including those in countries operating the world's most advanced networks, have found Huawei equipment to present a compelling technological solution and attractive value proposition.

93. As Huawei's revenue share has increased around the world, however, its position in the United States has been stunted. Huawei entered the North American market in 2008, but since then its revenue share in all RAN equipment has been consistently low in each year.[142] In 2010, eight senators asked the president to intervene when Huawei attempted to bid to provide telecommunications equipment to Sprint Nextel, a major U.S. carrier at the time.[143] This bid was excluded by Sprint Nextel largely due to national security concerns.[144] Softbank Group Corp, a Japanese information industry company that acquired Sprint Nextel in 2013,[145] promised U.S. authorities to remove Huawei's equipment from Sprint Nextel's newly acquired Clearwire Corp networks.[146] In addition, in 2011, the U.S. House

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[139] Comments of Huawei Technologies Co., LTD and Huawei Technologies USA, Inc., *In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, Before the Federal Communications Commission, Washington, D.C., 20554, WC Docket No. 18-89, June 1, 2018, p. 5.

[140] LTE-Advanced Pro, also known as 4.5G, is a set of 3GPP-approved technologies that bring LTE capabilities closer to 5G. LTE-Advanced Pro offers lower latency, improved reliability, and higher speeds compared to the previous technology generations. See Zhou Dongfei, "On the path to 5G with 4.5G," Huawei, October 18, 2016, at https://www.huawei.com/en/about-huawei/publications/communicate/80/reaching-5g-with-45g.

[141] "China's Huawei set to lead global roll-out of 5G mobile networks," *South China Morning Post*, February 23, 2018, at https://www.scmp.com/tech/enterprises/article/2134498/chinas-huawei-set-lead-global-roll-out-5g-mobile-networks.

[142] "TOTAL MOBILE RADIO ACCESS NETWORK (GSM+CDMA+WCDMA+WiMAX+LTE+5G NR)," Dell'Oro Group, Q1 2019.

[143] David Barboza, "Scrutiny for Chinese Telecom Bid," *The New York Times*, August 22, 2010, at https://www.nytimes.com/2010/08/23/business/global/23telecom.html.

[144] Joann S. Lublin and Shayndi Raice, "Security Fears Kill Chinese Bid in U.S," *Wall Street Journal*, November 5, 2010, at https://www.wsj.com/articles/SB10001424052748704353504575596611547810220.

[145] "Sprint and SoftBank Announce Completion of Merger," Sprint Press Release, July 10, 2013, at https://newsroom.sprint.com/sprint-and-softbank-announce-completion-of-merger.htm.

[146] Danny Yadron and Spencer E. Ante, "Sprint and Softbank Agree to Forgo, Remove Huawei Equipment, Lawmaker Says," *Wall Street Journal*, March 28, 2013, at https://blogs.wsj.com/washwire/2013/03/28/sprint-and-softbank-agree-to-forgo-remove-huawei-equipment-lawmaker-says/; Sprint Corporation, Form 10-K for the fiscal year ended December 31, 2013, pp. 2, 25.

of Representatives Permanent Select Committee on Intelligence initiated an investigation into Huawei and ZTE to "inquire into the counterintelligence and security threat posed by Chinese telecommunications companies doing business in the United States."[147] The committee's report concluded that the United States should "view with suspicion the continued penetration of the U.S. telecommunications market by Chinese telecommunications companies." It recommended placing restrictions on the use of Huawei's and ZTE's equipment by U.S. government systems and strongly encouraged private sector entities to seek vendors other than Huawei and ZTE for their projects.[148]

94. The NDAA for the Fiscal Year 2018, Section 1656, prohibited the procurement of Huawei's and ZTE's equipment for certain government uses, starting December 2018.[149] The NDAA for Fiscal Year 2019, Section 889, places additional restrictions on the procurement and use of Huawei's equipment by the government and federal contractors starting in August 2019.

95. As discussed above, Huawei's revenue share in North America is significantly lower than its revenue share in the rest of the world. In Dell'Oro Group's data, North America consists only of the United States and Canada. Because Canada is a small country (Canada has less than one-tenth the number of wireless subscriptions as the United States[150]), the data show that the major exception to Huawei's leading presence in RAN sales is the United States. Huawei's presence in the United States is primarily limited to serving small rural carriers.[151] Because the use of Huawei equipment was not restricted in Canada in 2018

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[147] "Investigative Report on the U.S. National Security Issues Posed by Chinese Telecommunications Companies Huawei and ZTE," A report by Chairman Mike Rogers and Ranking Member C.A. Dutch Ruppersberger of the Permanent Select Committee on Intelligence, U.S. House of Representatives, 112th Congress, October 8, 2012, p. iv.

[148] "Investigative Report on the U.S. National Security Issues Posed by Chinese Telecommunications Companies Huawei and ZTE," A report by Chairman Mike Rogers and Ranking Member C.A. Dutch Ruppersberger of the Permanent Select Committee on Intelligence, U.S. House of Representatives, 112th Congress, October 8, 2012, p. 45.

[149] John S. McCain National Defense Authorization Act for Fiscal Year 2018, § 1656(b)(1) and (c).

[150] Canada had 31.693 million mobile cellular subscriptions in 2017, compared to 391.6 million subscriptions in the United States. 31,693,000/391,600,000 = 8.1 percent. See "Statistics: Mobile-cellular subscriptions," International Telecommunications Union, at https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx.

[151] Jeff Johnston, "Equipment Ban Creates Static for Rural Telecom Operators," CoBank, June 2019, p. 1.

and was used by two of Canada's three largest carriers,[152] it is likely that Huawei's revenue share in the United States in 2018 was even lower than its revenue share in North America.

96. In North America, sales are essentially split between Ericsson and Nokia. Samsung is the third largest vendor, with a much smaller share of revenues. ZTE, another Chinese company whose sales in the United States have been restricted by U.S. government policy, had no RAN sales in North America in 2018.

97. The countries that use Huawei network equipment have among the fastest networks in the world, while U.S. wireless network performance ranks poorly in a global comparison.

98. Opensignal, a leading company in measuring network coverage and performance, conducts ongoing studies of wireless network performance on a variety of metrics, including download speed and latency.[153] By Opensignal's metrics, the 4G networks in the United States currently rank 30th among nations in download speed, 39th in upload speed, and 50th in latency. In download speed, the 4G networks in the United States rank behind 21 European countries, 4 Asian countries, Australia, New Zealand, Qatar, and Canada.[154] The 4G networks in many (if not all) of the best-performing countries use Huawei equipment, including the top three in download speed: South Korea,[155] Norway,[156] and Canada.[157]

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[152] See Josh Wingrove, "Canada Puts Huawei 5G Decision on Back Burner With Allies Split," May 8, 2019, *Bloomberg*, at https://www.bloomberg.com/news/articles/2019-05-08/canada-puts-huawei-5g-decision-on-back-burner-with-allies-split.

[153] "About us," Opensignal, at https://www.opensignal.com/about/about-us. See also, "Understanding mobile network experience: What do Opensignal's metrics mean?" *Opensignal Insights*, at https://www.opensignal.com/blog/2019/01/03/understanding-mobile-network-experience-what-do-opensignals-metrics-mean.

[154] Peter Boyland, "The State of Mobile Network Experience: Benchmarking mobile on the eve of the 5G revolution," Opensignal, May 2019, pp. 3 and 9, at https://www.opensignal.com/sites/opensignal-com/files/data/reports/global/data-2019-05/the_state_of_mobile_experience_may_2019_0.pdf.

[155] Collaborate to Commercially launch the World's First Uplink 2 CC CA Technology," Huawei Press Release, April 29, 2016, at https://www.huawei.com/en/press-events/news/2016/4/World-First-Uplink-2-CC-CA-Technology.http://english.chosun.com/site/data/html_dir/2019/06/18/2019061801409.html.

[156] Sveinung Sleire, "Norway Mulls Huawei 5G Decision That's Not 'Black and White'" *Bloomberg*, March 25, 2019, at https://www.bloomberg.com/news/articles/2019-03-25/norway-mulls-huawei-5g-decision-that-s-not-black-and-white.

[157] Mark Gollom, "Banning Huawei from building new 5G wireless network won't really hurt Canada's big telecom firms," *CBC News*, December 19, 2018, at https://www.cbc.ca/news/business/huawei-ban-government-bell-telus-5g-1.4950521.

99. The strong demand for Huawei's products across the globe is shown in RAN sales of 2G, 3G, and 4G equipment. Using the data provided to me by Dell'Oro Group, I calculated Huawei's revenue share of RAN sales by technology (i.e., GSM, CDMA, WCDMA, and LTE) and by region. The data show that in every region outside of North America, Huawei is a leading equipment provider in every technology. The data also show that although 5G deployment is nascent, in the regions where carriers have deployed 5G networks and where Huawei is not restricted (i.e., Europe, Middle East and Africa, and Asia Pacific), Huawei has a substantial (and often the largest) revenue share in 5G sales as well.[158]

100. Most of the 5G RAN revenues from deployment in Asia Pacific are likely from 5G deployments in South Korea,[159] and all or almost all 5G RAN revenues in North America are likely from the deployments of 5G in the United States.[160] In Q4 2018-Q1 2019 in Asia Pacific, Samsung had the highest revenue share from sales of 5G RAN equipment and Huawei had the second highest revenue share from sales of 5G RAN.

101. The available facts suggest that Samsung's success in Asia Pacific is due largely to success in its home country and is unlikely to be predictive of its future 5G RAN revenue shares in other countries and regions. The data also indicate that even in South Korea, Huawei had a substantial revenue share, and in other regions where 5G is being deployed and Huawei is allowed to supply 5G RAN equipment, Huawei had the largest revenue share.[161]

102. Huawei's global leadership in 5G RAN equipment is also reflected in the number of commercial contracts it holds for deployment of 5G networks, which are good predictors of future sales. Public reports indicate that as of June 2019, Huawei had won 50 5G commercial contracts in 30 countries and shipped 150,000 5G base stations.[162]

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[158] These data are provided by Dell'Oro Group. Due to the confidentiality of these data, I am not able to publish the supporting data in this report.

[159] Only South Korea has launched 5G networks, and other countries in Asia Pacific that are close to deploying and launching 5G network only recently allocated spectrum for 5G. See Appendix D.

[160] No Canadian carrier has deployed a 5G network. See, Cindy Baker, "Mainstream launch of 5G expected in Canada in 2021," *IT World Canada*, May 2, 2019, at https://www.itworldcanada.com/article/mainstream-launch-of-5g-expected-in-canada-in-2021/417579.

[161] Based on the data provided by Dell'Oro Group.

[162] Sherisse Pham, "Huawei is still signing up 5G customers despite US Pressure," *CNN Business*, June 26, 2019, at https://www.cnn.com/2019/06/26/tech/huawei-ken-hu-mwc/index.html.

103. Huawei had won more 5G commercial contracts than its two main competitors, Ericsson and Nokia. Ericsson had won 21 5G commercial contracts as of June 2019, and Nokia had won 42 as of June 2019.[163] ZTE had won 25 5G commercial contracts as of June 2019.[164] No information on the number of 5G commercial contracts is available for Samsung.

104. Despite Nokia's large number of 5G commercial contracts, its revenues from the early 5G deployments are quite low compared to those of the other three vendors.[165] Nokia's relatively low revenues in context of its significant number of commercial contracts might be a consequence of the fact that Nokia was at least three months behind its scheduled equipment delivery to South Korea's three carriers.[166] News articles report that one of the carriers, KT, decided to replace Nokia equipment with Samsung equipment because of delays in Nokia's supply.[167] In addition, analysts reported quality problems with Nokia's 5G equipment related to data processing capacity, radio interferences, and dual connectivity. Some carriers found that the performance of Nokia's equipment was inferior to that of Samsung, Huawei, and Ericsson.[168] As a result, areas where Nokia's equipment is installed in South Korea were reported to be removed from 5G coverage maps.[169]

105. In the next section I will explain factors behind Huawei's success, including its industry-leading investments in R&D and experience developing and implementing technologies crucial to 5G deployment.

[163] "Live 5G networks and publicly announced 5G contracts," *Ericsson*, June 12, 2019, at https://www.ericsson.com/en/5g/5g-networks/5g-contracts; Sherisse Pham, "Nokia is fighting hard to steal Huawei's 5G crown," *CNN Business*, at https://edition.cnn.com/2019/06/04/tech/huawei-5g-nokia/index.html.

[164] "ZTE secures 25 5G commercial contracts," *Yahoo Finance*, June 25, 2019, at https://finance.yahoo.com/news/zte-secures-25-5g-commercial-063100842.html.

[165] Based on the data provided by Dell'Oro Group.

[166] Michael Herh, "Nokia Equipment Causes Trouble for Korea's 5G Service Providers," *Business Korea*, April 23, 2019, at http://www.businesskorea.co.kr/news/articleView.html?idxno=31165.

[167] Michael Herh, "Nokia Equipment Causes Trouble for Korea's 5G Service Providers," *Business Korea*, April 23, 2019, at http://www.businesskorea.co.kr/news/articleView.html?idxno=31165.

[168] Michael Herh, "Nokia Equipment Causes Trouble for Korea's 5G Service Providers," *Business Korea*, April 23, 2019, at http://www.businesskorea.co.kr/news/articleView.html?idxno=31165.

[169] Michael Herh, "Nokia Equipment Causes Trouble for Korea's 5G Service Providers," *Business Korea*, April 23, 2019, at http://www.businesskorea.co.kr/news/articleView.html?idxno=31165.

VII. HUAWEI HAS UNIQUE CHARACTERISTICS WHOSE CONTINUED ABSENCE WILL DELAY THE U.S. TRANSITION TO 5G

106. Huawei possesses a unique combination of characteristics among equipment vendors. Continued exclusion of Huawei from the U.S. market will likely impede and delay U.S. carriers' progress toward 5G deployment and 5G penetration.

107. Huawei provides unique value because of (1) its global leadership in R&D in terms of investment, patent production, and other measures of R&D; and (2) its leadership in key 5G technologies, especially Massive MIMO and the technologies that underlie Massive MIMO.

A. Huawei Is an R&D Leader in 5G

108. Huawei has invested more in total R&D spending than any other major network equipment vendor in every year since 2012.[170]

109. Huawei stated in its annual report that it has been heavily investing in 5G since 2009[171] and that innovation is one of its main priorities:

> Innovation and research are our lifeblood, and we will continue to invest over 10% of our annual revenue in R&D. In 2018 alone, our R&D investment exceeded 100 billion yuan, ranking fifth globally in *The 2018 EU Industrial R&D Investment Scoreboard*. Our continued investment has produced positive results, giving us the ability to provide our customers with innovative products and more efficient services.[172]

110. Figure VII.1 shows Ericsson's, Nokia's, and Huawei's R&D investment from 2009 through 2018. Huawei has invested more in total R&D spending than any other major network equipment vendor in every year since 2013 and has invested more than Ericsson and Nokia combined in each of the last four years.

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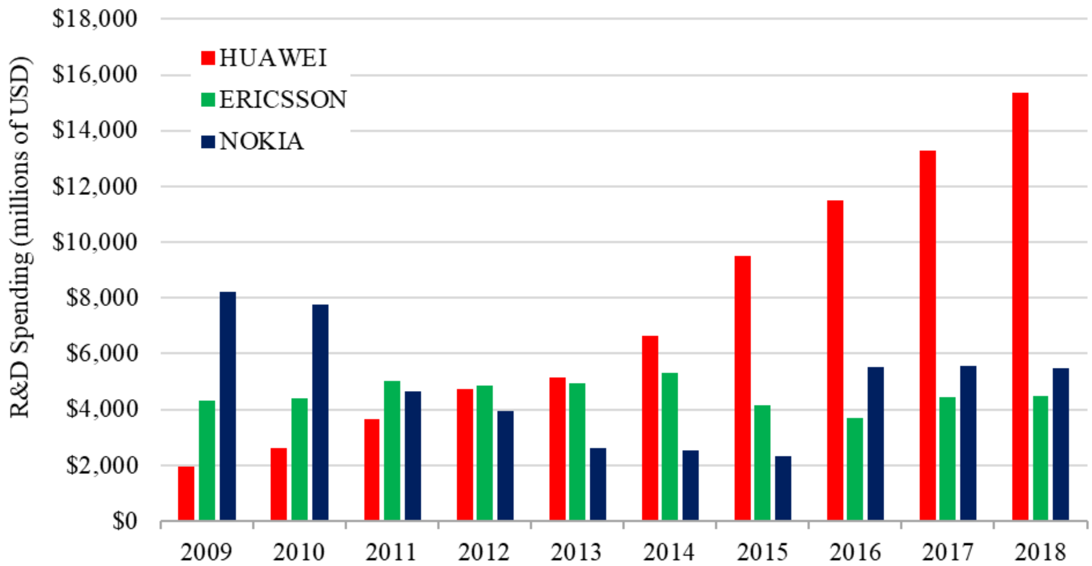
[170] Here I focus on R&D spending of the top three vendors. Based on their revenue shares in the market for RAN equipment, these are the only three carriers that have sufficient revenue shares to invest comparable amounts of resources in RAN R&D. See Figure VI.1.

[171] Huawei Investment & Holding Co., Ltd., 2017 Annual Report, p. 20.

[172] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 3.

111. The figure also shows that Huawei’s R&D spending has been growing over the entire period, unlike the R&D investments of the other two vendors. Nokia’s R&D investment declined overall from 2009 to 2018, and Ericsson’s investment over the same period remained at approximately the same level, with small variations.

Figure VII.1
Total R&D Spending (in Millions) of Top 3 RAN Equipment Vendors, 2009-2018[173]



Note: Ericsson reports its research and development spending in millions of Swedish kronor (SEK). Nokia reports its research and development spending in millions of euros (EUR). Huawei reports its research and development spending in millions of Chinese yuan (CNY). I converted all research and development spending data into millions of U.S. dollars (USD), using annual exchange rates.

112. In 2018, the Scoreboard, the European Commission's report on companies' R&D spending, ranked Huawei among the top 3 ICT producers by R&D in the world and among

[173] "Sweden / U.S. Foreign Exchange Rate, Swedish Kronor to One U.S. Dollar, Annual, Not Seasonally Adjusted," Federal Reserve Bank of St. Louis, accessed July 29, 2019, at https://fred.stlouisfed.org/series/DEXSDUS#; "U.S. / Euro Foreign Exchange Rate, U.S. Dollars to One Euro, Annual, Not Seasonally Adjusted," Federal Reserve Bank of St. Louis, accessed July 29, 2019, at https://fred.stlouisfed.org/series/DEXUSEU#; "China / U.S. Foreign Exchange Rate, Chinese Yuan to One U.S. Dollar, Annual, Not Seasonally Adjusted," Federal Reserve Bank of St. Louis, accessed July 29, 2019, at https://fred.stlouisfed.org/series/DEXCHUS#; Telefonaktiebolaget LM Ericsson, 2011 Annual Report, p. 46; Telefonaktiebolaget LM Ericsson, 2012 Annual Report, p. 48; Telefonaktiebolaget LM Ericsson, 2013 Annual Report, p. 51; Telefonaktiebolaget LM Ericsson, 2014 Annual Report, p. 56; Telefonaktiebolaget LM Ericsson, 2015 Annual Report, p. 56; Telefonaktiebolaget LM Ericsson, 2016 Annual Report, p. 54; Telefonaktiebolaget LM Ericsson, 2017 Annual Report, p. 33; Telefonaktiebolaget LM Ericsson, 2018 Annual Report, p. 45; "Nokia in 2011," Nokia Corporation, 2012, p. 20; Nokia Corporation, Nokia Annual Report on Form 20-F 2012, p. F-2; Nokia Corporation, Nokia Annual Report on Form 20-F 2013, p. F-2; Nokia Corporation, Nokia Annual Report on Form 20-F 2014, p. 142; Nokia Corporation, Nokia Annual Report on Form 20-F 2015, p. 140; Nokia Corporation, Nokia Annual Report on Form 20-F 2016, p. 144; Nokia Corporation, Nokia Annual Report on Form 20-F 2017, p. 148; Nokia Corporation, Nokia Annual Report on Form 20-F 2018, p. 130; Huawei Technologies Co., Ltd., 2010 Annual Report, p. 24; Huawei Technologies Co., Ltd., 2011 Annual Report, p. 32; Huawei Technologies Co., Ltd., 2012 Annual Report, p. 37; Huawei Technologies Co., Ltd., 2013 Annual Report, p. 55; Huawei Technologies Co., Ltd., 2014 Annual Report, p. 60; Huawei Technologies Co., Ltd., 2015 Annual Report, p. 53; Huawei Technologies Co., Ltd., 2016 Annual Report, p. 57; Huawei Technologies Co., Ltd., 2017 Annual Report, p. 64; Huawei Technologies Co., Ltd., 2018 Annual Report, p. 71.

the top 5 of all companies by R&D investment in the world. In comparison, Nokia was ranked 27th and Ericsson was ranked 43rd among all companies by R&D investment in the world.[174]

113. The results of this investment are apparent in Huawei's success in developing 5G technology. For example, Huawei has declared the largest share of 5G standard essential patent families ("SEPs") among all 5G patent owners.[175] According to IPlytics, a company that collects and analyzes patent data and provides tools for patent data analysis,[176] Huawei owned 1,554 5G SEP families as of April 2019. Nokia was the second largest owner after Huawei with 1,427 5G SEP families; Samsung was third with 1,316 5G SEP families; ZTE was fifth with 1,208 5G SEP families; and Ericsson was seventh with 819 5G SEP families.[177]

114. IPlytics also provides statistics on companies' contributions to 5G standards development. Technology standards are developed in international meetings at which companies submit and present technical papers. Huawei is the leader in the number of submitted 5G technical contributions (10,844) to 5G standard development. Ericsson submitted 8,428 contributions; Nokia submitted 5,843 contributions; Samsung submitted 2,621; and ZTE submitted 2,341.[178]

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[174] Samsung was ranked the top company by R&D investment in the world and the top ICT producer by R&D investment in the world. However, unlike for Huawei, Nokia, and Ericsson, for Samsung, network equipment is not its main line of business. The financial reporting practices by Samsung do not allow me to isolate Samsung's R&D investment in its network equipment business. I have no basis to conclude that Samsung's R&D investment in its network equipment business, and in RAN equipment in particular, is on par with the R&D investment of Huawei, Ericsson, or Nokia. See "EU R&D Scoreboard: The 2018 EU Industrial R&D Investment Scoreboard," *European Commission – Joint Research Centre*, 2018, Table 1.5 and Figure 4.1; Interim Consolidated Financial Statements of Samsung Electronics Co., Ltd. and Its Subsidiaries," Samsung Electronics Company, Ltd., as of March 31, 2019, p. 14; "Earnings Release Q1 2019," Samsung Electronics, April 2019, p. 2.

[175] "Who is leading the 5G patent race? A patent landscape analysis on declared SEPs and standards contributions." *IPlytics*, April 2019 (hereafter, *2019 IPlytics Report*), Table 2, at https://www.iplytics.com/wp-content/uploads/2019/01/Who-Leads-the-5G-Patent-Race_2019.pdf. SEPs are patented technologies that are designated as necessary for execution of the standard. A vendor manufacturing equipment that complies with the 5G standard, for example, must use the invention claimed by a SEP to comply with the standard.

[176] *2019 IPlytics Report*, p. 7.

[177] *2019 IPlytics Report*, Table 2.

[178] 2019 *IPlytics Report*, Table 5.

115. The attendance of engineers from each company at standards meetings is another measure of how invested the company is in technology development. Huawei is the technology leader by this measure as well, sending far more engineers to the meetings than any other vendor.[179]

116. Additionally, Huawei's commitment to R&D is reflected in its participation in international technical organizations. Huawei is an active member of more than 400 standards organizations, industry alliances, and open source communities.[180]

117. Huawei is also a leader with respect to the number of employees involved in R&D. Huawei reported that in 2018 more than 80,000 employees (45 percent of its total workforce) were involved in R&D.[181] Ericsson reports 24,800 employees (26 percent of its total workforce) working on R&D.[182] Nokia's 2017 "People and Planet" report states that Nokia employed approximately 103,000 people, out of which more than a third (approximately 34,333 employees) worked in R&D.[183]

118. Huawei has received multiple awards for its contributions to 5G technology. Examples of these awards are:

- In 2015, Huawei received the Biggest Contribution to 5G Development award at the 5G World Summit for its contributions relating to research and innovation in 5G technologies.[184]

- At the Mobile World Congress 2017, Huawei received the Outstanding Contribution for LTE Evolution to 5G award, Huawei's Network Function Virtualization ("NFV") solution won the Best Technology Enabler award,

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[179] 2019 *IPlytics Report*, pp. 5-6.
[180] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 58.
[181] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 44.
[182] Ericsson Annual Report, 2018, pp. 1, 35.
[183] "People and Planet Report 2017," Nokia Corporation, p. 5.
[184] "Huawei wins award at 5G World Summit 2015," *Daily Observer*, July 3, 2015, at http://www.observerbd.com/2015/07/03/97711.php.

and Huawei's active antenna unit ("AAU") solution won the Best Mobile Infrastructure award.[185]

- In 2017, Huawei's work conducting 5G pre-commercial tests with over 30 leading carriers was recognized as one of the World Leading Internet Scientific and Technological Achievements.[186]

- In June 2017, Huawei received the Best 5G Core Development award at the 5G World Summit held in London.[187]

- In December 2017, "Huawei 3GPP 5G Pre-commercial System," an end-to-end network equipment solution that encompasses RAN and core equipment, was awarded as one of World Leading Internet Scientific and Technological Achievements at the fourth World Internet Conference in Wuzhen, China.[188]

- In 2018, the GSM Association ("GSMA"), an organization that represents the interests of mobile operators and that produces the Mobile World Congress events,[189] awarded Huawei the "Outstanding Contribution to the Mobile Industry Award." This award recognizes individuals, companies, and organizations that have contributed to the advancement of mobile communications in significant ways.[190]

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[185] Huawei Investment & Holding Co., Ltd., 2017 Annual Report, pp. 24, 26; "Huawei's AAU Solution Awarded Best Mobile Infrastructure at MWC 2017," Huawei, February 28, 2017, at http://carrier.huawei.com/en/Trends-and-insights/AAU-Solution-Awarded-Best-Mobile-Infrastructure?ic_source=fmsh17.

[186] Huawei Investment & Holding Co., Ltd., 2017 Annual Report, p. 24.

[187] Huawei Investment & Holding Co., Ltd., 2017 Annual Report, p. 26.

[188] "Huawei 3GPP 5G Pre-commercial System is awarded as one of World Leading Internet Scientific and Technological Achievement at the Fourth World Internet Conference," Huawei Press Release, December 03, 2017, at https://www.huawei.com/en/press-events/news/2017/12/Huawei-3GPP-5G-Pre-commercial-System.

[189] "About Us," GSM Association, at https://www.gsma.com/aboutus/.

[190] "Huawei Named as Winner of 2018 GSMA Award for Outstanding Contribution to the Mobile Industry," February 26, 2018, GSMA Press Release, at https://www.gsma.com/newsroom/press-release/huawei-named-winner-2018-gsma-award-outstanding-contribution-mobile-industry/.

- In February 2019, Huawei won the "Market Development Award" from the Global TD-LTE Initiative ("GTI")[191] "for its outstanding performance in the 5G commercial market and for its promotion of the end-to-end 5G industry."[192]

B. Huawei's 5G RAN Equipment Is More Highly Ranked Than 5G RAN Equipment of Its Competitors

119. The quality of Huawei's 5G product portfolio has also been demonstrated in head-to-head comparisons. GlobalData, a market research firm headquartered in the United Kingdom,[193] compared 5G mobile base station portfolios offered by Huawei, Ericsson, Nokia, Samsung, and ZTE[194] on the following four criteria: (1) baseband unit capacity, (2) breadth of radio unit portfolio, (3) ease of installation, and (4) technology evolution. GlobalData found Huawei's 5G RAN equipment to lead in every category.[195]

120. A recent study by RootMetrics[196] also documents the quality of Huawei's equipment. RootMetrics tested performance of 5G networks deployed by major carriers KT, LG Uplus, and SK Telecom in South Korea in the high-population areas in Seoul and in suburban areas around Seoul. The 5G networks were tested between June 28, 2019 and July 6, 2019.[197]

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[191] GTI is the global initiative that advocates cooperation among carriers to promote LTE-TDD. "Global TD-LTE Initiative (GTI) Announced to Promote the Deployment of TD-LTE Networks," *PRNewswire-Asia*, February 14, 2011, at https://www.prnewswire.com/news-releases/global-td-lte-initiative-gti-announced-to-promote-the-deployment-of-td-lte-networks-116176069.html.

[192] "Huawei Wins 'Market Development Award' from GTI for its Outstanding Performance in 5G Commercialization," Huawei Press Release, February 22, 2019, at https://www.huawei.com/us/press-events/news/2019/2/huawei-wins-market-development-award-from-gti.

[193] "Why GlobalData," GlobalData, at https://www.globaldata.com/who-we-are/why-globaldata/.

[194] "Telecom industry's first 5G RAN competitive analysis published by GlobalData reveals Huawei leadership," GlobalData Press Release, July 25, 2019, at https://www.globaldata.com/telecom-industrys-first-5g-ran-competitive-analysis-published-by-globaldata-reveals-huawei-leadership/.

[195] "Telecom industry's first 5G RAN competitive analysis published by GlobalData reveals Huawei leadership," GlobalData Press Release, July 25, 2019, at https://www.globaldata.com/telecom-industrys-first-5g-ran-competitive-analysis-published-by-globaldata-reveals-huawei-leadership/.

[196] RootMetrics is a mobile analytics firm that provides insights into the user experience of mobile networks. "Providing insights to help improve the end-user mobile experience," RootMetrics by IHS Markit, at http://rootmetrics.com/en-US/about.

[197] "5G First Look South Korea," RootMetrics by IHS Markit, at http://rootmetrics.com/en-US/content/5g-first-look-south-korea-US.

121. RootMetrics reported the results for download speeds, availability, reliability, and latency.[198] The study found that all three carriers had excellent reliability for getting connected and staying connected to 5G networks.[199] It also found that LG Uplus delivered the fastest median and maximum 5G download speeds, had the most consistent speed performance, and had the lowest median download latency among all tested networks.[200]

122. It is reported that 90 percent of LG Uplus's network in the tested areas uses Huawei 5G equipment including Huawei 5G Massive MIMO equipment, which I will discuss in the next section.[201] Neither KT nor SK Telecom uses Huawei equipment in their 5G networks. KT and SK Telecom use 5G RAN supplied by Samsung, Ericsson, and Nokia.[202] These results are consistent with Huawei's leading position in 5G RAN.

123. As these facts and results show, Huawei is a global R&D leader in 5G RAN. Huawei invests heavily in R&D, both monetarily and in human resources, and its investment bears results in creating expertise that is memorialized in the quality and efficiency of its products.

C. Huawei's Massive MIMO Equipment Is in Far Greater Demand Than That Available from Any Other Vendor

124. One of the key components of 5G RAN is known as "Massive MIMO." Massive MIMO (multiple input, multiple output[203]) is antenna technology that deploys a large number of

[198] Reliability shows the frequency of download failures when attempting to access 5G network and the frequency of download failures after connecting to 5G network. See "5G First Look South Korea," RootMetrics by IHS Markit, at http://rootmetrics.com/en-US/content/5g-first-look-south-korea-US.

[199] RootMetrics graded download reliability as "excellent" if successful download was achieved at a rate of 97 percent. See "5G First Look South Korea," RootMetrics by IHS Markit, at http://rootmetrics.com/en-US/content/5g-first-look-south-korea-US.

[200] "5G First Look South Korea," RootMetrics by IHS Markit, at http://rootmetrics.com/en-US/content/5g-first-look-south-korea-US.

[201] See "South Korea's 5G Network Test Announcement: Huawei Definitely Boosts LG U+ to Come out Ahead," C114, August 13, 2019 (translated from Chinese), at http://www.c114.com.cn/news/126/a1097014.html.

[202] Iain Morris, "Samsung Pumps Up the Basestations [*sic*] in Korean 5G Market," *LightReading*, April 11, 2019, at https://www.lightreading.com/mobile/5g/samsung-pumps-up-the-basestations-in-korean-5g-market/d/d-id/750772.

[203] Edison Lee and Timothy Chau, "Telecom Services: The Geopolitics of 5G and IoT," *Jefferies Franchise Note*, September 14, 2017, p. 11.

two-dimensional arrays of active antennas at the base station.[204] Massive MIMO technology is an evolution of MIMO antenna technology;[205] Massive MIMO antennas generally have at least 32 antennas at the base station.[206] MIMO systems increase signal strength and deliver focused beams that can track user handsets and user equipment.[207] The large number of focused antenna elements allow the base station to concentrate its energy where it is needed, thereby reducing interference and achieving a much higher network capacity and better coverage.[208]

125. MIMO antennas were developed for and used in 4G wireless networks.[209] Massive MIMO antenna systems have also been used in LTE networks to improve capacity and coverage,[210] and this technology is expected to be a critical component of 5G deployment.[211] According to some reports, adequate 5G performance requires Massive MIMO to have a minimum of 64 antennas, and up to 256.[212] Massive MIMO is anticipated to be used in mid-band and mmW spectrum bands,[213] but not in low spectrum bands, because the longer wavelengths

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[204] Edison Lee and Timothy Chau, "Telecom Services: The Geopolitics of 5G and IoT," *Jefferies Franchise Note*, September 14, 2017, p. 4.

[205] Thomas L. Marzetta, *et al*., FUNDAMENTALS OF MASSIVE MIMO, Cambridge: Cambridge University Press, 2016, p. 5.

[206] Matti Passoja, "5G NR: Massive MIMO and Beamforming – What does it mean and how can I measure it in the field?," RCRWireless, September 12, 2018, https://www.rcrwireless.com/20180912/5g/5g-nr-massive-mimo-and-beamforming-what-does-it-mean-and-how-can-i-measure-it-in-the-field; "A closer look at Massive MIMO," Sprint Business, November 7, 2018, at https://business.sprint.com/blog/massive-mimo/.

[207] Edison Lee and Timothy Chau, "Telecom Services: The Geopolitics of 5G and IoT," *Jefferies Franchise Note*, September 14, 2017, p. 20.

[208] Edison Lee and Timothy Chau, "Telecom Services: The Geopolitics of 5G and IoT," *Jefferies Franchise Note*, September 14, 2017, p. 20.

[209] "4x4 MIMO Boosts 4G and Gives Consumers a Taste of the Gigabit Experience," *Strategy Analytics*, November 2017, p. 4.

[210] "4x4 MIMO Boosts 4G and Gives Consumers a Taste of the Gigabit Experience," *Strategy Analytics*, November 2017, p. 16-17.

[211] "4x4 MIMO Boosts 4G and Gives Consumers a Taste of the Gigabit Experience," *Strategy Analytics*, November 2017, p. 18.

[212] Edison Lee and Timothy Chau, "Telecom Services. The Geopolitics of 5G and IoT," *Jefferies Franchise Note*, September 14, 2017, p. 20.

[213] Narcis Cardona, Luis M. Correia, Daniel Calabuig, "Key Enabling Technologies for 5G: Millimeter-Wave and Massive MIMO," *International Journal of Wireless Information Networks* 24, iss. 3 (September 2017), pp. 201-202.

of the lower spectrum bands require antennas that are too large to be accommodated by Massive MIMO.[214]

126. Dell'Oro Group's data show that that Massive MIMO has accounted and will account for the vast majority of total 5G RAN spending over Q4 2018-Q1 2020. Sales of Massive MIMO are projected by analyst Dell'Oro Group to comprise an overwhelming majority of total 5G RAN spending in the last three quarters of 2019, before declining in 2020.

127. The evidence suggests that Huawei has the most advanced Massive MIMO products available today. Multiple sources, including the U.S. Department of Defense, conclude that Chinese equipment manufacturers, and Huawei in particular, have been leaders in Massive MIMO technology.[215]

128. A report by ABI Research, a New-York-based industry research firm,[216] compared and ranked "the ten most dominant and innovative mobile cellular antenna manufacturers in the world."[217] These included ACE Technologies, Amphenol, Comba, CommScope, Huawei, Kathrein, MOBI, RFS, Rosenberger, and Tongyu.[218] ABI Research analyzed the following characteristics of each vendor: "multi-band, ultra-wideband, active, and advanced MIMO capabilities, essential intellectual property and R&D, overall market

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[214] "Professor Rappaport Explains Why T-Mobile 5G 600 MHz Ultimately Doesn't Make It," Wireless One, May 3, 2018, at http://wirelessone.news/10-r/1037-professor-rappaport-explains-why-t-mobile-5g-600-mhz-are-a-dud.

[215] A report from the Defense Innovation Board called Huawei and ZTE "the leader [*sic*] in massive MIMO radio systems." See Milo Medin and Gilman Louie, "The 5G Ecosystem: Risks & Opportunities for DoD," Defense Innovation Board, April 2019, p. 17; Rethink Technology Research said that "Huawei has been in front of the field in areas such as Massive MIMO and flexible spectrum usage." See Caroline Gabriel, "Nokia and Ericsson pin hopes on 5G to catch up with Huawei," *Riot*, August 2018, at https://rethinkresearch.biz/articles/nokia-and-ericsson-pin-hopes-on-5g-to-catch-up-with-huawei-2/. According to the Wall Street Journal, European carriers said that Nokia and Ericsson "have been slow to release equipment as advanced as Huawei's." See "Huawei's dominance in 5G technology makes it nearly impossible to restrict the controversial Chinese company from telecom networks," *Wall Street Journal*, video at 2:24, at https://www.wsj.com/video/why-it-almost-impossible-to-extract-huawei-from-telecom-networks/122E816F-856B-4D3F-A361-B832D9862A99.html.

[216] "About Us: Who We Are," ABI Research, at https://www.abiresearch.com/pages/about-abi-research/; "Office Locations," ABI Research, at https://www.abiresearch.com/contact/.

[217] "Huawei and Kathrein Ranked Top Two Base Station Antenna Vendors in New ABI Research Competitive Assessment," ABI Research press release, August 8, 2019, at https://www.abiresearch.com/press/huawei-and-kathrein-ranked-top-two-base-station-antenna-vendors-new-abi-research-competitive-assessment/.

[218] "Huawei and Kathrein Ranked Top Two Base Station Antenna Vendors in New ABI Research Competitive Assessment," ABI Research press release, August 8, 2019, at https://www.abiresearch.com/press/huawei-and-kathrein-ranked-top-two-base-station-antenna-vendors-new-abi-research-competitive-assessment/.

share, antenna geographical penetration, financial and organizational health, and antenna portfolio."[219]

129. ABI Research ranked Huawei as the top vendor in innovation and implementation, followed by Kathrein (which is in the process of being acquired by Ericsson[220]) in the second place and CommScope in the third place. ABI Research reported that in 2018 Huawei was the largest antenna manufacturer in the market, and its market share (34.4 percent) was almost double the market share of its nearest competitor Kathrein (19.6 percent).[221]

130. Huawei's leadership in Massive MIMO technology may be the result of two factors in addition to Huawei's overall R&D leadership documented earlier.

131. First, Massive MIMO technology emerged from LTE-TDD,[222] a technology in which Huawei has unusually extensive expertise, as I explain below. There are two common technologies through which radio communications systems can communicate in both directions (i.e., to transmit and to receive a signal): TDD and FDD. The TDD method uses the same frequency channel to transmit and receive signals from a given handset or device but allocates different time slots for transmission and reception.[223] FDD uses different frequency channels, one for transmission and one for reception.[224]

[219] "Huawei and Kathrein Ranked Top Two Base Station Antenna Vendors in New ABI Research Competitive Assessment," ABI Research press release, August 8, 2019, at https://www.abiresearch.com/press/huawei-and-kathrein-ranked-top-two-base-station-antenna-vendors-new-abi-research-competitive-assessment/.

[220] According to news articles, this acquisition is expected to close in the third quarter of 2019. See "Ericsson buys antenna and filters business of Germany's Kathrein," *Reuters*, February 25, 2019, at https://www.reuters.com/article/us-kathrein-m-a-ericsson-idUSKCN1QE0SF.

[221] "Huawei and Kathrein Ranked Top Two Base Station Antenna Vendors in New ABI Research Competitive Assessment," ABI Research press release, August 8, 2019, at https://www.abiresearch.com/press/huawei-and-kathrein-ranked-top-two-base-station-antenna-vendors-new-abi-research-competitive-assessment/; "Huawei's innovation capability continues to lead, and the global passive antenna market share reaches 34.4%," C114, August 30, 2019 (translated from Chinese), at http://www.c114.com.cn/news/126/a1099418.html.

[222] Daryl Schoolar, "Massive MIMO Comes of Age," Ovum, 2017, p. 3.

[223] "LTE FDD, TDD, TD-LTE Duplex Schemes," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/4g-lte-long-term-evolution/tdd-fdd-td-lte-duplex-schemes.php.

[224] "LTE FDD, TDD, TD-LTE Duplex Schemes," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/4g-lte-long-term-evolution/tdd-fdd-td-lte-duplex-schemes.php.

132. Although there is an FDD version of Massive MIMO, I understand that the majority of Massive MIMO currently deployed uses TDD technology.[225] This is because Massive MIMO achieves spectrum efficiency by directing its beams to specific locations where it detects devices, a process called "beamforming."[226] From a lay perspective, because TDD uses only one frequency channel to both transmit and receive while FDD uses separate frequency channels for transmission and reception, the real-time calculations necessary to identify and direct the beams to and from mobile devices need only be done (at each point in time) once under TDD rather than twice, a material saving in complexity.[227] TDD Massive MIMO is more widespread than FDD Massive MIMO due to these properties of the TDD technology that simplify the algorithm for the beamforming technology.[228]

133. Few carriers in the world operate LTE-TDD networks; LTE-FDD is by far the more commonly deployed 4G technology.[229] Huawei, however, has extensive LTE-TDD expertise because TD-SCDMA evolved into LTE-TDD, and TD-SCDMA, as noted earlier, was developed in China and adopted by the largest[230] Chinese carrier, China Mobile.[231] Currently, China Mobile is the largest LTE-TDD carrier in the world,[232] and Huawei is one

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[225] Daryl Schoolar, "Massive MIMO Comes of Age," Ovum, 2017, p. 3.

[226] "Massive MIMO," Sprint, at https://business.sprint.com/5g/massive-mimo/.

[227] "A closer look at Massive MIMO," Sprint Business, November 7, 2018, at https://business.sprint.com/blog/massive-mimo/.

[228] Daryl Schoolar, "Massive MIMO Comes of Age," Ovum, 2017, p. 3.

[229] LTE TDD is also called TD-LTE. See "LTE FDD, TDD, TD-LTE Duplex Schemes," *Electronics Notes*, at https://www.electronics-notes.com/articles/connectivity/4g-lte-long-term-evolution/tdd-fdd-td-lte-duplex-schemes.php; "GSA confirms 521 LTE networks launched, LTE-Advanced now mainstream," Global mobile Supplier Association, August 12, 2016, at https://gsacom.com/press-release/gsa-confirms-521-lte-networks-launched-lte-advanced-now-mainstream/.

[230] Approximately 60 percent of mobile connections in China were through China Mobile in Q4 2018. 925,069,000/1,543,105,000 = 59.9 percent. See GSMA Intelligence 2019 subscriber data for China.

[231] Pete Bell, "4G Breaks Through That Great Chinese Wall," *TeleGeography*, August 24, 2016, at https://blog.telegeography.com/4g-market-in-china-subscriber-growth-of-china-mobile.

[232] Edison Lee and Timothy Chau, "Telecom Services. The Geopolitics of 5G and IoT," *Jefferies Franchise Note*, September 14, 2017, p. 9.

of the suppliers of LTE equipment to China Mobile.[233] As a result, Huawei had the largest revenue share of sales of LTE-TDD equipment among all vendors between 2011 (when the sales of LTE-TDD equipment started)[234] and 2018.[235]

134. Huawei's deep experience in LTE-TDD has allowed Huawei to leverage its TDD expertise into Massive MIMO antenna technology.

135. Huawei's leadership in Massive MIMO technology shows in Huawei's revenue share in sales of Massive MIMO equipment used in LTE networks. Dell'Oro data indicates that Huawei is by far the largest supplier of Massive MIMO for LTE. Its revenue share in 2018 exceeded that of the next largest supplier by a factor of over 9.[236]

136. Huawei has also been a leader in sales of Massive MIMO used in 5G deployments. Data on the early deployments of 5G show that Huawei and Samsung were the largest suppliers of 5G Massive MIMO in Q4 2018 and in Q1 2019.[237]

137. The surprising increase in Samsung's share of Massive MIMO sales for 5G relative to LTE is likely reflective of the facts that, as noted earlier, South Korea was one of the major deployers of 5G during the time period covered by the data and that Samsung has a substantial share of equipment sales in South Korea, its home country. Ericsson was able to more than double its revenue share from 2018 to Q1 2019, likely due to its partnership with Sprint, which was using Massive MIMO to roll out its 5G network in the United

[233] In 2011, Huawei named China Mobile as one of its "key customers." See Huawei Investment & Holding Co., Ltd., 2011 Annual Report, p. 93, at https://www.huawei.com/ucmf/groups/public/documents/attachments/hw_126991.pdf. In 2013, Huawei stated that it is a "strategic partner" of China Mobile. See Huawei Investment & Holding Co., Ltd., 2013 Annual Report, p. 29, at https://www.huawei.com/ucmf/groups/public/documents/attachments/hw_u_323372.pdf. In 2014, Huawei stated that it had become "the most important strategic partner of China Mobile...in the area of LTE construction." See Huawei Investment & Holding Co., Ltd., 2014 Annual Report, p. 22, at https://www-file.huawei.com/-/media/corporate/pdf/annual-report/annualreport2014_en.pdf?la=en-us. Huawei helped China Mobile to deploy the world's largest VoLTE network. See Huawei Investment & Holding Co., Ltd., 2016 Annual Report, p. 23, at https://www-file.huawei.com/-/media/CORPORATE/PDF/annual-report/AnnualReport2016_en.pdf?la=en; Huawei Investment & Holding Co., Ltd., 2017, p. 26, at https://www-file.huawei.com/-/media/corporate/pdf/annual-report/annual_report2017_en.pdf?la=en.

[234] "MOBILE RADIO ACCESS NETWORK – LTE – FDD," Dell'Oro Group, Q1 2019.

[235] Based on data provided by Dell'Oro Group.

[236] Based on data provided by Dell'Oro Group.

[237] Based on data provided by Dell'Oro Group.

States.[238] Huawei's substantial revenue shares were achieved despite having no sales of 5G Massive MIMO in the United States.

VIII. Continuing to Limit Huawei's Participation in the U.S. Market Will Delay the U.S. Transition to 5G

138. Continuing to exclude Huawei from the U.S. market will impede U.S. deployment of 5G and harm the U.S. economy.

A. Early Deployment of New Wireless Technology Benefits a Country

139. Leadership in a new generation of wireless technology benefits a country. Recon Analytics, a market research firm focusing on the telecommunications industry,[239] defines leadership in each generation of wireless technology as the status of being among the first to deploy a working network and being among the first to reach material levels of penetration and adoption of the technology.[240] Recon Analytics argues that the benefits of such leadership include "the strong economic contributions of wireless manufacturers to their balance of trade, the employment of hundreds of thousands, and the generation of intellectual capital and property rights."[241]

140. Deloitte has found that the global leaders in previous generations of wireless networks were rewarded greater macroeconomic benefits than non-leading countries.[242] Deloitte predicts that being a leader in 5G will generate even more benefits than did leadership in earlier technologies due to positive network effects associated with the billions of devices that will connect to 5G networks.[243] Deloitte argues that as more devices connect to 5G networks, companies will be able to collect and analyze data in order to provide more valuable

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[238] "Sprint Lights Up True Mobile 5G in Atlanta, Dallas-Fort Worth, Houston and Kansas City," Sprint Press Release, May 30, 2019, at https://newsroom.sprint.com/sprint-lights-up-true-mobile-5g-in-atlanta-dallas-fort-worth-houston-and-kansas-city.htm.

[239] "About Us," *Recon Analytics*, at http://reconanalytics.com/about-us/.

[240] *Recon Analytics Report 2018*, p. 3.

[241] *Recon Analytics Report 2018*, p. 4.

[242] "5G: The chance to lead for a decade," Deloitte, 2018, p. 2.

[243] In economics, a network effect occurs when the value of a product or service depends on the number of users. "5G: The chance to lead for a decade," Deloitte, 2018, p. 2.

services.[244] As a result, "countries that adopt 5G first are expected to experience disproportionate gains in macroeconomic impact compared to those that lag."[245]

B. Impacts of Wireless Telecommunications Technology on Economic Growth and Productivity

141. Economic analysis demonstrates that telecommunications technology boosts GDP. Indeed, the relationship between mobile broadband technology (and the telecommunications industry in general) and economic growth has been studied by economists for several decades.

142. There are a number of channels through which mobile telecommunications contribute to GDP.

143. First, deployment of mobile infrastructure directly benefits the economy through expenditures made by carriers and through jobs generated during infrastructure deployment. I refer to these contributions to GDP as "direct" effects.

144. Second, there are also "indirect" effects that are significant for telecommunications technologies, because telecommunications technologies enable innovation and productivity gains in many other sectors throughout the economy.[246] For example, as elaborated earlier, telecommunications enable services ranging from traditional telephony to video calls, mobile banking, video streaming, online games, tele-working,[247] GPS-based services, e-commerce, and transportation services, among many others. Modern telecommunications technology enables users to collaborate and exchange information over long distances and access and exchange data while they travel. Innovation enabled by new telecommunications technology leads to the production of new applications and devices, creation of companies, and improvements in ways of working, living, and

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[244] "5G: The chance to lead for a decade," Deloitte, 2018, p. 2.

[245] "5G: The chance to lead for a decade," Deloitte, 2018, p. 2.

[246] Harald Gruber and Pantelis Koutroumpis, "Mobile telecommunications and the impact on economic development," *Economic Policy* (July 2011) (hereafter, *Gruber and Koutroumpis (2011)*), p. 390, at https://www.jstor.org/stable/41261993?seq=1#metadata_info_tab_contents; Timothy F. Bresnahan and Manuel Trajtenberg, "General purpose technologies 'Engines of growth'?" *Journal of Econometrics* 65, no. 1 (1995), p. 84.

[247] *Gruber and Koutroumpis (2011)*, p. 392.

learning.[248] These innovative services and goods improve productivity and contribute to the overall growth of the economy.[249]

145. The development of the 5G ecosystem and of the extensive array of new services and industries arising from 5G will all amplify GDP growth. 5G is anticipated to enable innovation in transport, logistics, IoT, electricity distribution, public safety, health and wellness, and smart cities.[250] An Accenture study on 5G deployment predicts that, between direct and indirect effects, the rollout of 5G could create up to 3 million additional jobs and annually boost GDP by $500 billion in the United States.[251]

146. The indirect effects of telecommunications technology, such as the production of new applications and devices, become more pronounced as more individuals use the technology.[252] Several economic studies have estimated the effect of availability and penetration of a mobile technology on GDP.

147. Economists Robert Crandall and Charles Jackson evaluated the impact on the U.S. economy of faster roll-out of broadband access, including both wireless and landline. They concluded that the benefits are substantial:

> [A] reasonable figure for the total annual benefits to the U.S. economy of the widespread adoption of broadband access in all its forms—ADSL, cable modems, satellites, 3G wireless, and others—could be more than 400 billion dollars per year. Faster rollout of high-speed access services gives us these benefits

[248] "The impact of 4G technology on commercial interactions, economic growth, and U.S. competitiveness," Deloitte, August 2011, p. 2.

[249] *Gruber and Koutroumpis (2011)*, p. 392.

[250] See 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Release 15 Description; Summary of Rel-15 Work Items (Release 15), TR 21.915 v1.0.0 (2019-03), pp. 9-10.

[251] "Smart Cities: How 5G Can Help Municipalities Become Vibrant Smart Cities," *Accenture Strategy*, 2017, at https://www.accenture.com/t20170222T202102__w__/us-en/_acnmedia/PDF-43/Accenture-5G-Municipalities-Become-Smart-Cities.pdf, p. 3. Accenture estimates the *overall* effect that 5G deployment and penetration will have on GDP and employment over seven years. In my report in Section VIII.E, I estimate the effect of *delay* in 5G deployment and penetration on GDP and employment over the 2019-2024 period. Because I estimate the effect on employment using a multiplier approach discussed in detail in Section VIII.E.iv, the delay in 5G deployment affects employment only in years 2019 and 2020 (as I explain in Section VII.E.iv, after 2020 the investment in 5G catches up with what the investment would have been without a delay in 5G deployment). Due to these differences, the effects on GDP and employment that I estimate in Section VIII.E are substantially lower than the effects on GDP and employment estimated by Accenture.

[252] *Gruber and Koutroumpis (2011)*, p. 390.

> earlier. A reasonable estimate of the net present value of faster rollout of broadband is as much as 500 billion dollars. Under the more modest scenario of 50 percent adoption, the net present value of faster rollout would be about 140 billion dollars.[253]

148. Economists Harald Gruber and Pantelis Koutroumpis, using panel data from 192 countries over the 1990-2007 period, found that an increased number of mobile lines, which is their proxy for the diffusion of mobile telecommunications,[254] results in higher GDP growth.[255] Economist Harald Edquist and coauthors, using data for 90 countries over the 2002-2014 period, found that a 10 percent increase in mobile broadband adoption increases GDP by 0.8 percent.[256]

149. A study by Deloitte examined the impact of the penetration of a new generation of wireless technology on GDP, using data from the transition from 2G to 3G. The study examined a panel of 96 developed and developing countries over the 2008-2011 period to estimate the impact of the penetration rate of new 3G technology in a country on its GDP per capita. It found that a 10 percent increase in the 3G penetration rate increased GDP per capita by 0.15 percent.[257]

150. Just as increased technology penetration increases GDP, delays in technology penetration will dampen GDP growth. Economist Jerry Hausman estimated the losses to consumer welfare in the United States due to the delay in the introduction (and, therefore, in the availability and penetration) of cellular service in the United States, which was result of the FCC's regulatory indecision. Using price and subscribership data for the 1989-1993 period from a confidential survey of cellular carriers, Hausman estimated that annual consumer welfare loss ranged from \$16.7 billion to \$33.5 billion in 1994 dollars, which is

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[253] See Robert Crandall and Charles Jackson, "The \$500 Billion Opportunity," in DOWN TO THE WIRE: STUDIES IN THE DIFFUSION AND REGULATION OF TELECOMMUNICATIONS TECHNOLOGIES, ed. Allan Shampine (Nova Science Publishers, 2003), p. iv.

[254] *Gruber and Koutroumpis (2011)*, p. 396.

[255] *Gruber and Koutroumpis (2011)*, pp. 400-402, Table 2.

[256] Harald Edquist *et al.*, "How important are mobile broadband networks for the global economic development?" *Information Economics and Policy* 45 (2018), pp. 17, 19, Table 7.

[257] "What is the impact of mobile telephony on economic growth? A Report for the GSM Association." *Deloitte*, November 2012, pp. 2, 11, 13-14.

equivalent to welfare losses of $28.7 billion to $57.6 billion in 2019 dollars.[258] He also found that this regulatory indecision delayed the provision of cellular services by seven to ten years in the U.S., which in total translated into welfare losses ranging from $116.9 billion to $335 billion in 1994 dollars, which is equivalent to welfare losses of $200.9 billion to $575.7 billion in 2019 dollars.[259]

C. Continued Exclusion of Huawei Will Further Delay 5G Deployment and Penetration

151. As already noted, the evidence from data on 5G RAN equipment spending indicates that the United States is behind in 5G deployment. The most recently available data show that spending on 5G RAN equipment in North America is on the order of a third of that in Asia Pacific.[260]

152. The slow start of the United States in 5G deployment is undoubtedly due at least in part to the spectrum gap that I discussed earlier. It may not be possible for the United States to catch up to those countries that have already been deploying commercial 5G networks on a wide scale even once the FCC allocates mid-band spectrum for 5G use. History shows that countries that lag in initial penetration of a new technology tend to continue to lag behind for several years in that technology. Figure VIII.1 shows the 4G penetration rate

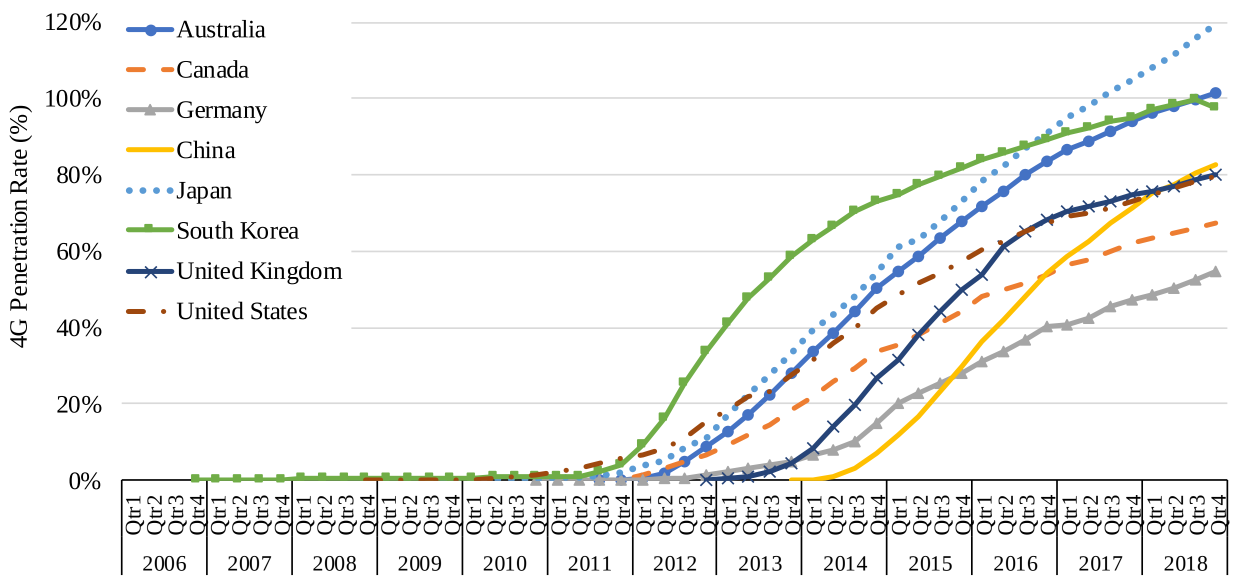
[258] Jerry Hausman, "Valuing the Effects if Regulation on New Services in Telecommunications," *Brookings Papers: Microeconomics* (1997), pp. 20, 23. I converted losses expressed in 1994 dollars into 2019 dollars by multiplying losses in 1994 by the ratio of CPI in 2019 to CPI in 1994. CPI for 1994 is calculated as the average of monthly CPIs in 1994. CPI for 2019 is calculated as the average of monthly CPIs from January 2019 through July 2019. See "Historical Consumer Price Index for All Urban Consumers (CPI-U): U.S. city average, all items, by month," Bureau of Labor Statistics, July 2019, at https://www.bls.gov/cpi/tables/supplemental-files/historical-cpi-u-201907.pdf.

[259] Jerry Hausman, "Valuing the Effects if Regulation on New Services in Telecommunications," *Brookings Papers: Microeconomics* (1997), pp. 20, 23. I converted losses expressed in 1994 dollars into 2019 dollars by multiplying losses in 1994 by the ratio of CPI in 2019 to CPI in 1994. CPI for 1994 is calculated as the average of monthly CPIs in 1994. CPI for 2019 is calculated as the average of monthly CPIs from January 2019 through July 2019. See "Historical Consumer Price Index for All Urban Consumers (CPI-U): U.S. city average, all items, by month," Bureau of Labor Statistics, July 2019, at https://www.bls.gov/cpi/tables/supplemental-files/historical-cpi-u-201907.pdf.

[260] See Section V.

over time for eight countries for which data are available to me. As the figure shows, many countries that start out behind tend to stay behind.[261]

Figure VIII.1
4G Penetration Rate - Selected Countries, Q1 2006 - Q4 2018



Source: GSMA Intelligence, "Country Dashboard," 2019, for Australia, Canada, China, Germany, Japan, South Korea, the United Kingdom, and the United States.

153. Because the United States is already delayed relative to other leading countries, the ability of the United States to become a leading country in 5G deployment and penetration will depend on its ability to recover quickly from its initial slow start. Recovering quickly will require, in turn, access to the best available equipment and fostering of the most competitive equipment market. The absence of Huawei—the market technology leader in 5G RAN technologies generally and in Massive MIMO technology in particular—will

[261] Using the data underlying this figure, I identified 27 country pairs, in which one country (the "follower country") launched 4G after the other country (the "leader country"). For example, in the country pair South Korea-Australia, South Korea is the leader country (it launched 4G in Q4 2006) and Australia is the follower country (it launched 4G in Q3 2011). Out of 27 country pairs, only 13 follower countries caught up with the leader countries. I consider that a follower country catches up with a leader country if its 4G penetration rate stays consistently equal to or above the 4G penetration rate of the leader country. I did not include country pair Australia-Canada in this analysis because Australia and Canada launched 4G networks in the same quarter.

inevitably damage the ability of the United States to regain lost ground to the extent it is possible.

154. There are several reasons that the continued absence of Huawei from the U.S. market will not only damage the ability of the United States to recover from its slow start in 5G deployment but will further delay it.

i. Huawei's RAN Equipment, Especially Massive MIMO, Is Among the Most Widely Used in the World, Thus Implying a More Developed Ecosystem that Facilitates Deployment and Adoption

155. As I discussed in Section VII, Huawei's RAN equipment, especially Massive MIMO, is among the most widely used globally. As more carriers adopt a particular technology its installation and use drive additional knowledge and foster the development of related equipment. Improved knowledge and a broader equipment portfolio in turn enhance the ease of installation and use of new networks, further accelerating deployment.

ii. Huawei's Competitive Presence Would Drive Down Prices of Other Vendors' RAN Equipment, Thus Encouraging Faster Deployment of 5G

156. The market for RAN equipment is highly concentrated in the United States. As I have discussed, there are only five RAN equipment vendors with the R&D muscle and capabilities to provide 5G RAN equipment in the world today, and only two of these have a substantial revenue share in the United States. The fact that the market for 5G RAN equipment is so highly concentrated in the United States inevitably causes equipment prices to be higher than they would be with additional competition from Huawei, the largest vendor of RAN equipment in the rest of the world today.[262] I will discuss this conclusion in greater detail in Section IX.

157. Correspondingly, permitting Huawei to sell in the United States would increase competition among equipment vendors for carriers' business and would be expected to

[262] Based on the data provided by Dell'Oro Group.

drive equipment prices down. The reduction in equipment prices would, in turn, allow carriers to deploy 5G networks more quickly for a given volume of capital expenditures.

iii. Simultaneous Deployment of 5G Around the World Imposes Pressure on the Global Supply Chain of RAN Equipment, Leading to Delays

158. As I have discussed in Section V.B.ii, carriers around the world are simultaneously deploying 5G networks, and many seek to be leaders in 5G deployment. Many countries are preparing to start rolling out 5G networks in addition to those already deploying 5G networks. To the extent that Ericsson, Nokia, and Samsung, the main suppliers of 5G RAN in the United States, have already made commitments to carriers in other countries to supply equipment, their ability to supply U.S. carriers may be limited in the short run. Indeed, as noted earlier, Nokia, one of the major U.S. suppliers, has already experienced delays in supplying equipment to South Korea.[263]

iv. Huawei's 5G RAN Equipment Is the Most Advanced in the World, and Its Absence Will Affect the Quality of Services Available to U.S. Mobile Wireless Customers, Thereby Depressing Customer Acceptance

159. As documented earlier, the data on acceptance of Huawei equipment as measured by both its revenue shares and its independent quality ratings indicate that Huawei sells the leading 5G equipment in the world today. As also documented, countries that use Huawei equipment in their 4G networks have on average far superior network performance than do U.S. networks. Even if U.S. carriers were able to deploy 5G networks equally quickly with or without Huawei in the marketplace, the evidence is that the quality of these networks would be inferior to their performance if Huawei 5G RAN equipment were included.

160. Penetration of a new technology depends not only on the availability of the network, but also on the benefits it provides over and above existing services to which customers have become accustomed. This is because adoption of a new technology, especially for early adopters, requires upgraded handsets.[264] Hence, the speed with which a significant number

[263] See Section VI.
[264] See Appendix D for examples of 5G-capable handsets.

of customers will transition to a new technology will be accelerated when the benefits of the new service are more attractive or otherwise more apparent to users. The speed with which penetration of 5G grows in the United States will, accordingly, be dampened from its starting point by exclusion of what is currently known as the leading equipment in the world.

D. Other Observers Have Also Concluded that Exclusion of Huawei Will Cause Delay in 5G Network Deployment

161. A study by U.K.-based analyst firm Assembly analyzed the impact of a partial or complete restriction on Huawei in the U.K. market for RAN equipment on carriers' 5G rollout timeline. In the course of this study, Assembly interviewed three out of the four major U.K. carriers.[265] Assembly found that the exclusion of Huawei from the United Kingdom would delay deployment there by 18 to 24 months, of which 9 to 18 months would be needed for Huawei's competitors to bridge the technological gap. The study also found that, depending on the severity of restriction, additional time might be required to replace Huawei's equipment in the existing networks.[266]

162. Policy makers and carriers have also concluded that placing restrictions on Huawei would result in significant delays in 5G deployment. For example, Telus Corp., a Canadian provider of wireless telecommunications services, has warned of potential delays in 5G deployment and added costs if Huawei's 5G network equipment is banned from the Canadian market.[267] The Wall Street Journal reported that according to some senior executives of wireless carriers, Huawei's 5G technology may be up to one year ahead of

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[265] "The Impact on the UK of a Restriction on Huawei in the Telecoms Supply Chain," Assembly, April 5, 2019, pp. 3, 6, 8-10, at http://www.mobileuk.org/The%20impact%20on%20the%20UK%20of%20a%20restriction%20on%20Huawei%20in%20the%20telecoms%20supply%20chain.pdf.

[266] "The Impact on the UK of a Restriction on Huawei in the Telecoms Supply Chain," Assembly, April 5, 2019, pp. 3, 8-10, at http://www.mobileuk.org/The%20impact%20on%20the%20UK%20of%20a%20restriction%20on%20Huawei%20in%20the%20telecoms%20supply%20chain.pdf.

[267] Natalie Wong, "Telus Warns of Potential Cost Fallout if Canada Bans Huawei," *Bloomberg*, February 14, 2019, at https://www.bloomberg.com/news/articles/2019-02-14/telus-says-huawei-ban-could-materially-raise-5g-deployment-cost.

its Western rivals.[268] A study by GSMA found that banning telecom equipment from Huawei and ZTE in Europe would delay deployment of 5G networks by about 18 months due to delivery challenges by vendors such as Nokia, Ericsson, and Samsung.[269] The chief technology officer of BT Group plc ("BT")—a U.K.-based communications services company that offers its services in 180 countries[270]—Howard Watson said at an industry event in March 2019 that Huawei's 5G technology was 18 months ahead of Ericsson's and Nokia's 5G technology.[271] BT's chief architect Neil McRae stated that "there is only one true 5G supplier right now and that is Huawei—the others need to catch up." He did not specify the extent of the technological gap between Huawei and its competitors.[272] In February 2019, a senior technology analyst at the research firm Fitch Solutions reported that based on his conversations with carriers Huawei is "far more advanced than the other two [Ericsson and Nokia] right now."[273]

E. The Economic Impact of the Delay of 5G Deployment on the U.S. Economy, Incorporating the Effects of Depressed Penetration

163. When a new technology is expected to generate considerable benefits for the economy, delaying or impeding the development of the infrastructure for that technology will lead to delayed penetration of the technology (i.e., delayed adoption of the technology by consumers and businesses), which will in turn inevitably generate substantial losses to the economy. I have applied econometric and economic techniques to quantify the effect on the U.S. economy of the incremental delay caused by Huawei's exclusion.

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[268] Wall Street Journal video, Sarah Krouse, "Huawei Presses Verizon to Pay for Patents," *Wall Street Journal*, June 12, 2019, at https://www.wsj.com/articles/huawei-presses-verizon-to-pay-for-patents-11560354414.

[269] Gwenaelle Barzic, "Europe's 5G to cost $62 billion more if Chinese vendors banned: telcos," *Reuters*, June 7, 2019, at https://www.reuters.com/article/us-huawei-europe-gsma/europes-5g-to-cost-62-billion-more-if-chinese-vendors-banned-industry-idUSKCN1T80Y3.

[270] BT Group plc, 2019 Annual Report, p. 4.

[271] Paul Lipscombe, "Scrapping Huawei could delay UK 5G rollout by up to two years," *Mobile News*, March 25, 2019.

[272] Ray Le Maistre, "BT's McRae: Huawei Is 'the Only True 5G Supplier Right Now,'" *Light Reading*, November 21, 2018, at https://www.lightreading.com/mobile/5g/bts-mcrae-huawei-is-the-only-true-5g-supplier-right-now/d/d-id/747734.

[273] Michelle Toh, "America's fight with Huawei is messing with the world's 5G plans" *CNN Business*, February 15, 2019, at https://edition.cnn.com/2019/02/14/tech/huawei-nokia-ericsson-5g/index.html.

i. Estimating the Effect of 5G Penetration on GDP

164. To estimate the effect of delayed 5G penetration on GDP, I first apply regression analysis to estimate the effect of 4G penetration on GDP. It is likely that the impact on GDP per capita of the transition from 4G to 5G will be at least as great as the impact on GDP per capita of the transition from 3G to 4G. One of the reasons that the transition to 5G would have a greater impact than did the transition to 4G is the substantial network effects that are predicted to be generated by billions of devices connected to 5G networks, as well as the virtuous cycle generated by the other applications of 5G discussed in Section IV.

165. To perform this estimation, I apply data from GSMA Intelligence on 4G penetration rates and total mobile penetration rates in Australia, Canada, Germany, Japan, South Korea, the United States, and the United Kingdom over the years 2012 to 2017. To isolate the effect of 4G wireless penetration on GDP I control for other factors, including the country's overall wireless penetration rate, country's net investment in nonfinancial assets, country's total supply of labor, and volume of trade measured as the sum of imports and exports. These variables, as well as data on GDP per capita, are taken from the World Bank's World Development Indicators ("WDI") database.[274]

166. My regression specification follows the regression specification developed in the 2012 Deloitte study[275] that I described in Section VIII.B, which estimated the effect of 3G penetration on GDP per capita.

167. I find that a one percentage point increase in the 4G penetration rate increased GDP per capita by 0.035 percent all else equal over the countries studied. This result is statistically significant and robust to modifications in the model specification. Details of this estimation are provided in Appendix B.

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[274] See "Databank. World Development Indicators," World Bank, at https://databank.worldbank.org/data/source/world-development-indicators.

[275] "What is the impact of mobile telephony on economic growth? A Report for the GSM Association." Deloitte, November 2012, pp. 13-14.

168. To put this result into context, an increase of 1 percent in the 4G penetration rate would have increased total GDP in Q2 2019 by approximately $7.5 billion, according to this estimate.[276]

ii. Modeling the Delay Due to the Absence of Huawei

169. Because it is impossible to predict precisely the extent of delay in 5G penetration that will result from Huawei's absence from the United States, I quantified the effects of delay under three reasonable delay scenarios. The estimates of delay time are based on reports of Huawei's 5G equipment advances over other vendors' 5G equipment and estimates by other observers already discussed in this report of delays due to the exclusion of Huawei from the U.S. market for RAN equipment.[277] These factors have led me to quantify the losses to the U.S. economy from delayed 5G penetration of 6, 12, and 18 months due to Huawei's absence from the U.S. market. My estimates quantify the effects of these delays over and above the effect of the delay already caused by and anticipated due to the U.S. spectrum gap.

170. Delayed entry of a product or service of a firm into a market may or may not have persistent effects as a general economic matter. For example, delayed entry by one product or service of a firm into an established market in which this firm already sells other products or services may have little or no persistent effects on that firm's ability to sell its product or service, depending on characteristics of the market, firm, distribution channels, and product or service. However, in some cases, delayed entry may accelerate the penetration rate of the delayed product or service offered by the later mover if the first mover has educated customers about the product category or technology, thereby overcoming initial resistance

[276] $7,468,237,717.5=$64,830*0.01*0.035*329,135,000. See "Population, Thousands, Quarterly, Not Seasonally Adjusted," Federal Reserve Bank of St. Louis, accessed August 16, 2019, at https://fred.stlouisfed.org/series/B230RC0Q173SBEA; "Gross domestic product per capita, Dollars, Quarterly, Seasonally Adjusted Annual Rate," Federal Reserve Bank of St. Louis, accessed August 19, 2019, at https://fred.stlouisfed.org/series/A939RC0Q052SBEA.

[277] See Section VIII.D.

to it, for example.[278] The existence, absence, or extent of persistent effects of delay are a factual matter that depend on the market circumstances.

171. The history of adoption at a national level of new generations of wireless technology buildout indicates that when infrastructure buildout is delayed and penetration of the technology is depressed, the delay will generally have persistent consequences. This is not surprising, because penetration of a new wireless technology such as 4G or 5G requires network buildout and capital expenditure location by location. Typically, carriers have neither the capital nor managerial capabilities to build out a new generation network at all nationwide locations simultaneously; rather, buildout occurs sequentially, beginning with most attractive or otherwise most feasible locations first. As a result, delaying the initiation of network upgrades sets back the entire trajectory of upgrades and, therefore, adoption of the new technology. Depressing nationwide adoption of a new generation of wireless technology in one quarter, for example, will affect the trajectory of adoption over future quarters, and it may take many years for the penetration rate to catch up to the level it would have achieved had it begun earlier.

172. To assess empirically the persistence of delayed deployment by a country of a new generation of wireless technology infrastructure, I performed an analysis of 4G penetration rate data for 8 countries over the Q1 2006-Q4 2018 period, depicted earlier in Figure VIII.1. Details of this analysis are provided in Appendix B.i. I found that delayed deployment of a new wireless technology does indeed have persistent effects over time and that while the effect varied from country to country, countries that were delayed in deployment of 4G tended not to catch up to earlier deployers for several years.

173. Based on the results of my data analysis, I assume that the impact of an initial delay in infrastructure deployment on overall penetration of the new technology generation will persist for five years and one quarter before the United States attains the penetration level it would have achieved but for the initial delay. That is, an initial delay of, for example,

[278] Theo Anderson, "The Second-Mover Advantage," based on the research of Venkatesh Shankar and Gregory Carpenter, Kellogg Insight, November 4, 2013, at https://insight.kellogg.northwestern.edu/article/the_second_mover_advantage.

six months would result in 5G penetration being six months behind the level it would otherwise have achieved at each point in time for five years and one quarter, after which time the 5G penetration rate reaches the 5G penetration rate the United States would have achieved but for the initial delay.[279]

iii. Calculation of the Effect of Delayed 5G Deployment on the U.S. Economy Due to Exclusion of Huawei

174. My purpose is to estimate the effect of delayed deployment due to Huawei's exclusion from the United States while also taking into account, and controlling for, the fact that the United States is also suffering a delay in 5G deployment due to the U.S. spectrum gap. Specifically, my methodology estimates the effect of the delay due to exclusion of Huawei over and above the effect on the economy of the delay due to the spectrum gap.

175. Hence, to estimate the effect on 5G penetration of a deployment delay in the United States due to Huawei's absence from the U.S. market, I first estimated the loss to the U.S. economy associated with a delay due to the spectrum gap in the United States alone.

176. U.S. carriers started deploying (very limited) 5G mobile commercial networks using spectrum available to them in Q1 2019.[280] Only when the FCC releases mid-band spectrum to carriers can all U.S. carriers start deploying 5G networks on a broad basis. I assume that had mid-band spectrum been available to all major U.S. carriers, they would have started deploying 5G on a broad basis in Q1 2019. The FCC has not yet set a date to release mid-band spectrum to major U.S. carriers, but FCC commissioner Ajit Pai has announced that the FCC intends to do so in 2019 or 2020.[281] I assume that mid-band spectrum will be made available to carriers in Q3 2019. If this schedule holds, the delay associated with the

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[279] This analysis is based on GSMA data on 4G penetration rates for Australia, Canada, China, Germany, Japan, South Korea, the United Kingdom, and the United States over Q4 2006-Q4 2018.

[280] See Appendix D.

[281] Specifically, in June 2019 Ajit Pai said in his testimony before the U.S. Senate Committee on Commerce, Science, and Transportation that "we intend to take action to make available more spectrum in the 2.5 GHz and 3.7-4.2 GHz bands in the coming months." He also stated that in 2020 the FCC intends to auction spectrum in the 3.5 GHz band and that the FCC expects to authorize initial commercial deployments in this band in summer 2019. Statement of Chairman Ajit Pai, Federal Communications Commission, Hearing on "Oversight of the Federal Communications Commission," Before the United States Senate Committee on Commerce, Science, and Transportation, June 12, 2019, available at https://docs.fcc.gov/public/attachments/DOC-357959A1.pdf.

spectrum gap will be approximately 6 months;[282] therefore, in my model I assume that the delay in deployment of 5G networks in the United States due to the U.S. spectrum gap is 6 months.[283]

177. Second, I estimate the losses to the U.S. economy associated with the cumulative delay due to the spectrum gap (6 months) and Huawei's continued exclusion (an additional 6, 12, or 18 months).

178. To calculate the incremental loss due to delay associated with Huawei's absence, I subtract the estimated loss due to delay associated with the spectrum gap from the estimated loss due to the cumulative delay associated with both the spectrum gap and Huawei's absence.

179. To perform these calculations, I model the 5G penetration rate in a scenario with no delay at all from Q2 2019 to Q1 2026 that would occur in the United States as following the same growth path as did the U.S. 4G penetration rate from Q1 2009 to Q4 2015.[284] I assume, however, that when deployment is delayed by time t, the penetration rate is also delayed by time t, and that the delay in penetration rate persists for five years and one quarter from the start of deployment, as discussed earlier. Figure VIII.2 shows the modeled trajectories

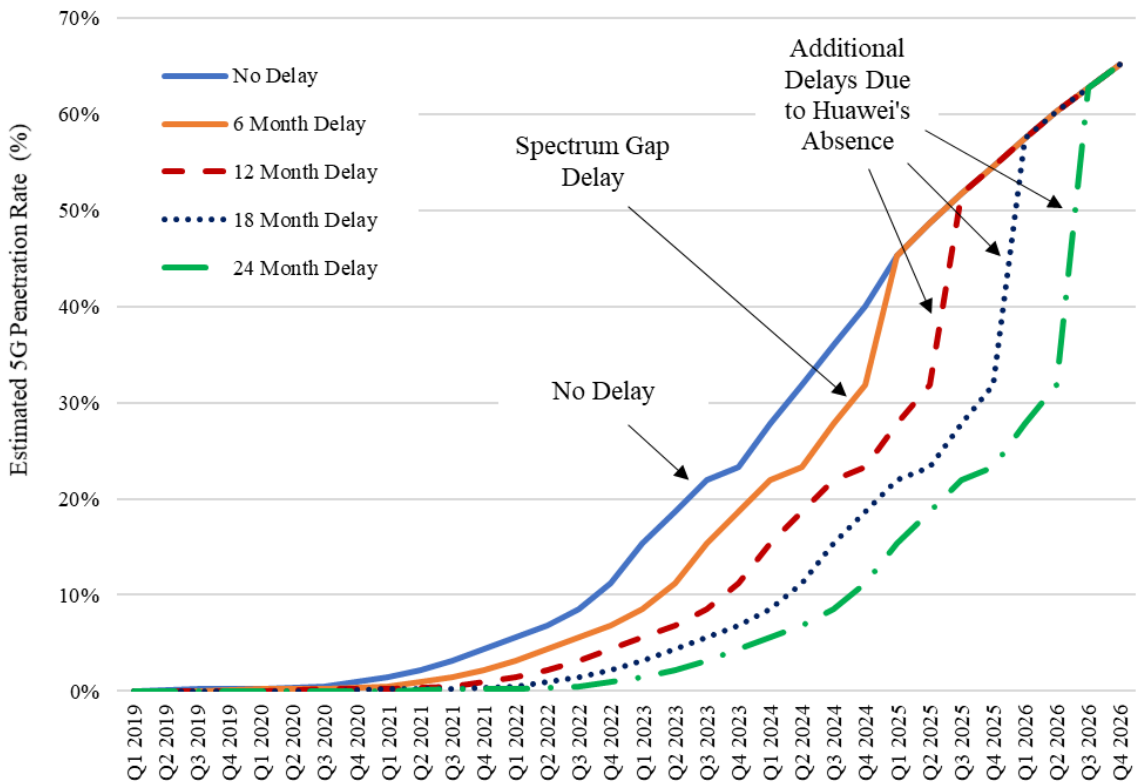
[282] Because the availability of 5G networks is very limited as of the writing of this report, I assume that 5G the penetration rate will remain close to zero until after mid-band spectrum is made available to carriers. See Appendix D for the state of 5G deployment in the U.S.

[283] The duration of delay associated with the spectrum gap is likely to be longer than 6 months, because generally spectrum reallocation is a long and complicated process. Even if the delay due to the spectrum gap is longer than 6 months, however, the additional delay in deployment due to Huawei's absence from the market is unlikely to shrink, because as Huawei and all other vendors continue to invest in continued development, Huawei is likely to preserve its technological lead over the other vendors of RAN equipment. I estimated losses associated with a longer spectrum gap and the same durations of delay due to Huawei's absence and found that the losses increase when the spectrum gap increases. Note that when the spectrum gap increases, the cumulative delay associated with the spectrum gap and Huawei's absence from the U.S. market may affect the penetration rate of 5G beyond 2024. Therefore, comparing the costs due to Huawei's absence from the U.S. market in the scenarios with longer spectrum gap delays requires estimating the decline in GDP over longer periods of time. For example, if the spectrum gap delay increases by 6 months (i.e., the spectrum gap is 12 months in total), assuming the same additional delay durations due to Huawei's absence, the economic losses to the U.S. over 2019-2026 increase by $19-50 billion depending on the duration of the additional delay due to Huawei's absence. My analysis is, therefore, conservative.

[284] Although the first 5G networks in the U.S. have launched, the availability of 5G remains very limited. Because no statistics on 5G subscribership are available in the U.S., I consider this to be a signal that there are very few 5G subscribers in the U.S. For the purposes of my model, I assume that the 5G penetration rate will remain close to zero until after mid-band spectrum is released to U.S. carriers. I assume that in a scenario with no delay (due to the spectrum gap or Huawei's absence from the U.S. market), the adoption of 5G in the U.S. would have started in Q2 2019, because this is when the first U.S. carrier Verizon launched its 5G mobile network using high-band spectrum.

of 5G penetration rate (1) in the scenario without any delay; i.e., a world in which the United States experienced no delay even due to the spectrum gap or due to an absence of Huawei from the market; (2) in the scenario in which the United States experiences the delay associated with the spectrum gap but no additional delay due to the absence of Huawei; and (3) in the scenarios with 12, 18, and 24 months delay, which result from the cumulative delay due to the spectrum gap and Huawei's absence from the U.S. market for RAN equipment.

Figure VIII.2
Estimated 5G Penetration Rate in the U.S. without Delay and with Delays of 6, 12, 18, and 24 Months Due to Spectrum Gap and Due to Absence of Huawei from the U.S. Market



Notes:
[1] I assume that without a delay in 5G deployment, the 5G penetration rate between Q2 2019 and Q4 2026 will replicate the 4G penetration rate between Q1 2009 and Q3 2016. I assume that if 5G deployment were delayed, the 5G penetration rate would follow the same trajectory as in the scenario without delay, but its start would be delayed by the time equal to the duration of delay and will remain delayed for twenty-one quarters, or 5.25 years, from the start of deployment in the scenario with delay; I assume that after 5.25 years, the 5G penetration rate in the scenario with delay will be equal to the 5G penetration rate in the same quarter from the scenario without delay. For example, when 5G deployment is delayed by six months, the 5G penetration rate is assumed to be zero in Q2 2019 and Q3 2019; for t = Q4 2019-Q4 2024 it is assumed that the 5G penetration rate in Q_t equals the 5G penetration rate from the scenario without delay in Q_{t-2}; and for t = Q1 2025-Q4 2026 it is assumed that the 5G penetration rate in Q_t equals the 5G penetration rate from the scenario without delay in Q_t.
[2] The FCC intends to release mid-band spectrum to carriers in 2019-2020, but no date has been set. I assume that mid-band spectrum will be released to carriers in Q3 2019; therefore, I assume that the delay associated with the spectrum gap is 6 months. I discuss the implications of a longer delay due to a spectrum gap in fn. 281.

Sources:
[1] GSMA Intelligence, "Country Dashboard," 2019, for the United States.
[2] Statement of Chairman Ajit Pai, Federal Communications Commission, Hearing on "Oversight of the Federal Communications Commission," Before the United States Senate Committee on Commerce, Science, and Transportation, June 12, 2019, available at https://docs.fcc.gov/public/attachments/DOC-357959A1.pdf.

180. To calculate the percentage point decline in the 5G penetration rate because of delay under each of my defined delay scenarios, I first calculated the average annual 5G penetration rate in the scenario with delay and without delay and then subtract the 5G penetration rate that would occur in the delay scenario from the 5G penetration rate that would occur if there were no delay in each year in which the delay is expected to persist. I limited my analysis to the 2019-2024 period.[285]

181. To calculate the effect of that reduced penetration on GDP, I multiplied my regression estimate of the effect on GDP per capita of a reduction in 5G penetration rate by the calculated decline in 5G penetration rate in each year. The product is the estimated percentage decline in GDP per capita in each year due to delay. I multiplied this percentage decline by the projected GDP per capita in that year to get an estimate of the decline in GDP per capita due to delay.

182. I translated the resulting estimated decline in per capita GDP into the estimated decline in total GDP by multiplying the estimated loss in GDP per capita by the projected population of the United States in each year.

183. The total reduction in GDP for each delay scenario is the sum of the GDP reductions in each year associated with that delay scenario discounted to 2019 at a social discount rate of 3.5 percent, as provided by economists Mark Moore and Aidan Vining for the United States [286]

184. Finally, to isolate the losses resulting from the absence of Huawei, I subtracted the estimated reduction in GDP resulting from the spectrum gap alone from the estimated reduction in GDP resulting from the cumulative delay due to the spectrum gap and

[285] In the scenario with the shortest duration of delay due to Huawei's absence from the U.S. market, I project that the U.S. catches up with the penetration rate in no delay scenario in Q1 2025. To simplify my analysis, I calculate losses for all delay scenarios over the 2019-2024 period.

[286] Social discount rate is the rate that is used in a cost-benefit analysis of a potential regulation or public project to calculate that project's net present value. The social discount rate is the annual percentage decline in a representative individual's utility from consuming the same bundle of goods or services in the future as opposed to the present. Mark A. Moore and Aidan R. Vining, "The Social Rate of Time Preference and the Social Discount Rate," *Mercatus Center: George Mason University* (2018), pp. 3 and 5, at https://www.mercatus.org/system/files/moore_and_vining_-_mercatus_research_-_a_social_rate_of_time_preference_approach_to_social_discount_rate_-_v1.pdf.

Huawei's exclusion. For example, to calculate the reduction in GDP caused by a 6-month delay due to a Huawei's absence, I estimate the cost resulting from a 12-month delay (a 6-month delay due to the spectrum gap plus a 6-month delay due to Huawei's exclusion) and subtract from it the estimated reduction in GDP associated with the 6-month delay resulting from spectrum gap alone. The detailed calculations are shown in Appendix B and Exhibit B.2.

185. The results of this analysis are presented in Exhibit VIII.1.

186. Exhibit VIII.1 shows that the impact of a delay in 5G deployment is substantial. Depending on the extent of the delay, the present discounted value of losses to the U.S. economy from Huawei's absence varies from approximately $104 billion (from a 6-month delay) to approximately $241 billion (from an 18-month delay) over the duration of delay. These estimated losses are over and above the costs to the economy associated with the spectrum gap alone.

Exhibit VIII.1
Total Losses Resulting from the Delay of 5G Deployment to the United States under Different Delay Scenarios, Discounted Present Value

Delay Duration	Decline in Total GDP Due to Delay Caused by Absence of Huawei, 2019-2024
6 Months	$ 103,646,561,838
12 Months	$ 182,024,710,760
18 Months	$ 240,671,885,050

Note: See notes and sources to Exhibit B.2.

iv. Calculation of the Effect of Delayed 5G Deployment on U.S. Employment Due to Exclusion of Huawei

187. Delayed deployment of 5G will have a ripple effect on the U.S. economy that will affect not only GDP but employment as well. Investment in the deployment of 5G networks will create new jobs that are required to deploy 5G networks and to support the additional goods and services whose purchase will be stimulated by those workers' income throughout the United States. Correspondingly, delayed 5G deployment means that some jobs will not be

created in the years in which investment spending on deployment is depressed. In this section I estimate the effect of investment in 5G RAN deployment on U.S. employment in years in which investment spending is depressed in the three delay scenarios—2019, 2020, and 2021.

188. Delay in 5G deployment will directly affect employment in industries related to the roll-out of 5G networks, such as construction, engineering, and others directly involved in the deployment of networks. Jobs lost in these industries are "direct" jobs lost.[287] Reduced employment in one industry also affects the employment in other industries. When jobs are lost in one industry and the output of that industry falls, other industries that supply inputs to that industry also lose jobs. These are "indirect" jobs lost.[288] In addition, jobs supported by the demand for goods and services purchased using the incomes of workers in these direct and indirect jobs will also suffer. For example, jobs in the construction industry support jobs at restaurants and grocery stores where employees engaged in construction and related activities eat and shop for food. These are "induced" jobs lost.[289] The sum of the effects on direct, indirect, and induced jobs is the total effect on employment of investment in 5G deployment.

189. The total effect of investment spending in a specific industry on employment is commonly estimated using so-called "input-output" multipliers, which show how many direct and indirect jobs are generated per $1 million in investment spending in a given industry. The input-output multipliers I apply in my analysis do not include induced effects on employment, which makes my estimate conservative.[290] To calculate how many jobs will be lost in 2019-2021 because of the delay in investment in 5G infrastructure, I use

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[287] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," Analysis Group, February 2019, p. 12.

[288] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," Analysis Group, February 2019, p. 12.

[289] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," Analysis Group, February 2019, p. 12.

[290] As I explain in this section, I use employment multipliers provided by the Bureau of Labor Statistics, and they do not include induced multiplier effects. See Richard W. Graham, "Employment Outlook: 2018-2028. Layout and Description For 205-Order Employment Requirements Tables: Historical 1997 through 2018," prepared in the Bureau of Labor Statistics Office of Occupational Statistics and Employment Projections, September 4, 2019, p. 6, at https://www.bls.gov/emp/data/emp-requirements.htm.

multipliers from what are called employment requirements tables, which are developed by the U.S. Bureau of Labor Statistics ("BLS"), an agency of the U.S. Department of Labor. These tables are provided annually, and they are based on the input-output tables developed by the U.S. Bureau of Economic Analysis ("BEA") supplemented with data from additional sources, such as data from the U.S. Census Bureau and from the U.S. Department of Agriculture.[291] These tables allow one to estimate the effect of spending on one industry's final goods and services on overall U.S. employment.[292,293] I use these multipliers to estimate how many more jobs would have been generated between 2019 and 2021 but for the delay in 5G investment due to the absence of Huawei from the U.S. market for RAN equipment.

190. Investment in 5G RAN infrastructure is not just an investment in one particular industry; instead, it involves investment in several industries. I rely on existing economic studies to

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[291] Richard W. Graham, "Employment Outlook: 2018-2028. Layout and Description For 205-Order Employment Requirements Tables: Historical 1997 through 2018," prepared in the Bureau of Labor Statistics Office of Occupational Statistics and Employment Projections, September 4, 2019, at https://www.bls.gov/emp/data/emp-requirements.htm.

[292] Economists also use RIMS II multipliers developed by the BEA to estimate the potential effects of various projects, such as investment in new infrastructure (e.g., building a new road or stadium) on regional economies' employment and output. The BEA, however, does not provide nationwide RIMS II multipliers. RIMS II multipliers are only available for states and counties. For this reason, I use multipliers provided by the BLS. See "RIMS II: An essential tool for regional developers and planners," Bureau of Economic Analysis, U.S. Department of Commerce, pp. iii, 1-1, at https://www.bea.gov/resources/methodologies/RIMSII-user-guide; "Frequently Asked Questions," Bureau of Economic Analysis, U.S. Department of Commerce, at http://commercedataservice.github.io/BEA_RIMS_Redesign/faq-page.html.

[293] The BLS notes that there are several limitation to the multipliers that it provides: (1) BLS assumes that the input-output relations are stable over time, which may not hold, especially in the long-run; (2) the price deflator applied by the BLS to the tables to remove the effects of relative price changes over time may cause distortions of data in the tables; (3) the estimated effect on employment using the BLS multiplier may include both part- and full-time jobs; (4) the effect estimates an increase in jobs and not an increase in employment; (5) the employment factors may vary even though the true productivity may or may not have changed; (6) the input-output tables do not distinguish between domestically produced and imported goods and assume domestic production techniques; these tables may overstate the impact of incremental investment on domestic employment; (6) the estimated relationships using input-output matrices are average relationships which may not hold on the margin; and (7) the input-output multipliers do not include the impact of spending on consumer goods and services that is funded by these workers' incomes generated by producing the goods and services. See Richard W. Graham, "Employment Outlook: 2018-2028. Layout and Description For 205-Order Employment Requirements Tables: Historical 1997 through 2018," prepared in the Bureau of Labor Statistics Office of Occupational Statistics and Employment Projections, September 4, 2019, at https://www.bls.gov/emp/data/emp-requirements.htm, pp. 5-6.

identify the industries involved in 5G RAN infrastructure deployment.[294] Specifically, I rely on a study by economists Jeffrey Eisenach, Hal Singer, and Jeffrey West which identifies the following industries involved in broadband deployment: (1) telephone apparatus manufacturing, (2) broadcast and wireless communications equipment, (3) fiber optic cable manufacturing, and (4) construction.[295] To estimate the share of investment spending on the goods and services of each industry, I rely on the methodology proposed by the Analysis Group study and calculate industry spending shares as the average of investment spending shares for broadband deployment estimated for the fiber-to-the-home industry and the wireless industry from the study by economists Jeffrey Eisenach, Hal Singer, and Jeffrey West.[296] See Exhibit VIII.2.

[294] I assume that the deployment of 5G RAN will require investment in the same industries in the same proportions as total 5G deployment.

[295] Jeffrey A. Eisenach, Hal J. Singer, & Jeffrey D. West, "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," Empiris LLC, prepared on behalf of the Fiber-To-The-Home Council (2009), p. 8.

[296] Jeffrey A. Eisenach, Hal J. Singer, & Jeffrey D. West, "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," Empiris LLC, prepared on behalf of the Fiber-To-The-Home Council (2009), p. 8; David W. Sosa and Greg Rafert, “The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States,” Analysis Group, February 2019, pp. 11-12 and Figure A-3.

Exhibit VIII.2
Shares of Investment Spending on 5G Infrastructure by Industry

Industry NAICS Code	Industry Name	Investment Spending Shares		Investment Spending Shares for 5G Infrustucture Investment
		Fiber-to-the-Home ("FTTH") Industry	Wireless Industry	
[A]	[B]	[C]	[D]	[E]=([C]+[D])/2
334210	Telephone apparatus manufacturing	30%	0%	15%
334220	Broadcast and wireless communications equipment	0%	93%	46.5%
335921	Fiber optic cable manufacturing	20%	0%	10%
230000	Construction	50%	7%	28.5%

Notes:
[1] I follow the same methodology as Sosa and Rafert (2019) in calculating weights of 5G infrastructure spending for the four industries as the average of the investment spending shares to the Fiber-to-the-Home and Wireless industries from Eisenach, Singer, and West (2009) paper.
[2] NAICS codes are North American Industry Classification System codes which are adopted by the U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics in their input-output data.

Sources:
[1] Jeffrey A. Eisenach, Hal J. Singer, and Jeffrey D. West, "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," Empiris LLC, prepared for Fiber-to-the-Home Council (2009), p. 8.
[2] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, Table A-3, p. 11.

191. Next, I use employment multipliers provided by the BLS for each of these industries and investment shares estimated in Exhibit VIII.3 to calculate a weighted average multiplier that I can apply to overall 5G RAN investment spending to estimate the incremental effect of 5G RAN investment spending on U.S. employment.

192. Three out of the four industries identified by Jeffrey Eisenach, Hal Singer, and Jeffrey West and included in Exhibit VIII.2 use six-digit North American Industry Classification System ("NAICS") codes. The BLS does not provide multipliers for detailed industries with six-digit level NAICS codes "334210," "334220," and "335921." The BLS provides data for more aggregated industries with four-digit level NAICS codes "3342" and "3359" which

contain within them the three detailed industries specified above.[297] I then used employment multipliers provided by the BLS for these two industries and for the construction industry (NAICS code "23") and applied spending shares from Exhibit VIII.2 to calculate the weighted average multiplier of 5G RAN investment on employment. I estimate that each $1 million in spending on 5G RAN deployment creates 4.73 jobs. See Exhibit VIII.3.[298]

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[297] Richard W. Graham, "Employment Outlook: 2018-2028. Layout and Description For 205-Order Employment Requirements Tables: Historical 1997 through 2018," prepared in the Bureau of Labor Statistics Office of Occupational Statistics and Employment Projections, September 4, 2019, at https://www.bls.gov/emp/data/emp-requirements.htm, p. 1 and the "SectorPlan312.xlsx" data file provided by the BLS; "North American Industry Classification System," United States, 2017, Executive Office of the President, Office of Management and Budget, pp. 31-32, 43, 44-45.

[298] The Analysis Group study estimated the employment multiplier for 5G deployment spending to be 8.66. This multiplier, according to the authors of this study, includes direct, indirect, and induced effects, whereas my estimated multiplier of 4.73 includes only direct and indirect effects and is therefore smaller compared to the Analysis Group estimate. See David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," Analysis Group, February 2019, pp. 11-12, Table A-3.

Exhibit VIII.3
Calculation of a Weighted Average Multiplier of 5G Infrastructure Investment on Employment

Industry NAICS Code	Industry Name	Investment Spending Share	Input-Output Employment Multiplier
3342	Communications equipment manufacturing	61.5%	2.93
3359	Other electrical equipment and component manufacturing	10.0%	6.07
23	Construction	28.5%	8.15
Weighted Average Multiplier			**4.73**

Notes:
[1] The data provided by the Bureau of Labor Statistics are only available for aggregated four-digit NAICS industry codes. I used aggregated industry input-output employment multipliers to calculate the weighted average input-output multiplier.
[2] The investment spending share for industry 3342 was calculated as the sum of investment spending shares for industries 334210 and 334220 from Exhibit VIII.2.

Sources:
[1] Exhibit VIII.2.
[2] Employment Requirement Matrix file "NOMINAL_EMPREQ_2018.csv," Bureau of Labor Statistics, U.S. Department of Labor, available at https://www.bls.gov/emp/data/emp-requirements.htm.
[3] Industry sectoring plan descriptions from "SectorPlan312.xlsx," Bureau of Labor Statistics, U.S. Department of Labor, available at https://www.bls.gov/emp/data/emp-requirements.htm.
[4] "North American Industry Classification System," United States, 2017, Executive Office of the President, Office of Management and Budget, pp. 31, 43, 44.

193. The Analysis Group study estimated that the total investment required to deploy 5G networks in the U.S. over a seven-year period would be $297.92 billion.[299] A report by Frontier Economics assumes that investment spending on RAN networks accounts for 25 percent of the total 5G investment.[300] Applying this estimate to the total 5G investment yields $74.48 billion investment in 5G RAN. Applying the weighted average multiplier

[299] The investment required for 5G deployment is estimated for five large U.S. providers: Verizon, AT&T, Sprint, T-Mobile, and U.S. Cellular. The amount of investment in 5G deployment is estimated based on the inflation-adjusted average capital spending of these five carriers from 2008 to 2017. See David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, pp. 7-9 and Figure A-1.
[300] "The value of competition to 5G network deployment," Frontier Economics, August 2018, p. 41.

from Exhibit VIII.3 to the estimate of 5G RAN investment yields 352.4 thousand job-years over the seven-year period, or 50.3 thousand jobs annually.[301]

194. If Huawei is absent from the U.S. market, a delay in 5G investment of 6 months would result in the loss of 25.2 thousand jobs in 2019. A delay in 5G investment of 12 months would result in the loss of 25.2 thousand jobs in 2019 and 25.2 thousand jobs in 2020. A delay of 18 months would result in the loss of 25.2 thousand jobs in 2019 and 50.3 thousand jobs in 2020. These results are summarized in Exhibit VIII.4.

[301] The total number of generated jobs over the seven-year period of deployment is calculated as follows: 352,442=$297,920,000,000*0.25*4.732 /$1,000,000. The number of generated jobs per year is calculated as follows: 50,349=352,442/7.

Exhibit VIII.4
Decline in Employment Due to Huawei's Absence from the U.S. Market for RAN Equipment under Different Delay Duration Scenarios

Delay Duration Due to Huawei's Absence	Decline in Employment Due to Absence of Huawei (in Number of Jobs)		Total Jobs Lost
	2019	2020	
6 Months	25,174	-	25,174
12 Months	25,174	25,174	50,349
18 Months	25,174	50,349	75,523

Notes:
[1] Under the 6-month delay scenario, deployment is delayed from Q3 2019 to Q1 2020; under the 12-month delay scenario, the deployment is delayed from Q3 2019 to Q3 2020; under the 18-month delay scenario, the deployment is delayed from Q3 2019 to Q1 2021. I calculate the employment effect only over the period in which 5G networks would have begun deployment in the presence of Huawei but would not in its absence; I conservatively assume that no jobs will be lost due to lower investment in 5G networks in any other quarter.
[2] Jobs lost in year *i* in each delay scenario are calculated as follows: 50,349 (number of jobs lost per year)*delay duration in months in year *i*/12 months, where *i* equals 2019 or 2020. For example, in the case of a 6-month delay, the delay in deployment starts in Q3 2019 and ends in Q1 2020; therefore, the number of jobs lost in 2019 equals 50,349*6/12 = 25,174. No jobs are lost in 2020 because there is no delay in deployment in this year under the scenario of 6-month delay.

Sources:
[1] David W. Sosa and Greg Rafert, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," *Analysis Group*, February 2019, pp. 7-9, 11-12.
[2] Exhibit VIII.3.
[3] "The value of competition to 5G network deployment," Frontier Economics, August 2018, p. 41.

IX. THE IMPACT ON THE COSTS OF RAN EQUIPMENT DUE TO REDUCED COMPETITION FROM EXCLUDING HUAWEI FROM THE U.S. MARKET FOR RAN NETWORK EQUIPMENT

195. In addition to the effects of excluding Huawei from the United States on GDP and employment due to the expected delay in investment in and adoption of 5G technology, continued exclusion of Huawei would harm the U.S. economy by reducing competition in the sale of 5G equipment relative to what it would be if Huawei were active in the U.S. market.

196. The current exclusion of Huawei has already increased market concentration in the U.S. market for RAN equipment and has likely substantially increased prices of RAN equipment in the U.S., as I show below. Going forward, the impact on market concentration and prices of RAN equipment, including 5G RAN equipment, may be somewhat greater, because additional restrictions imposed on Huawei's presence in the U.S. are likely to erode Huawei's already negligible revenue share in the U.S. market for RAN equipment.

197. As a general economic matter, it is to be expected that the marketplace for 5G RAN equipment, and for RAN equipment in general, would be more competitive if Huawei were in the market than if it continues to be absent from the market. As documented earlier, U.S. sales of wireless RAN equipment are highly concentrated among only two major vendors.[302] In the rest of the world, the market is generally served by three or more providers who have material revenue shares, and a significant share of the revenue accounted for by Huawei.[303] Huawei's substantial contribution to the market demonstrates that carriers have concluded that, in many circumstances, Huawei offers the best combination of price, service, and quality.

198. The participation of a respected vendor in the marketplace generally has the effect of invigorating competition among all of the participants. As a result, even if a purchaser selected a competitor other than Huawei, the additional competition from Huawei can drive the price offered by the other competitors down relative to the price they would have charged in the absence of the additional competition from Huawei.[304] For example, economist Allan Shampine found that higher industry concentration in North America is associated with higher prices for RAN equipment in general and for LTE base stations in particular, though he did not provide a quantification of the effect.[305]

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[302] See Section VI.

[303] Based on data provided by Dell'Oro Group.

[304] The additional competition can have additional beneficial effects on the marketplace, including accelerating innovation that is targeted to the needs of U.S. carriers. I discussed this effect in previous sections and do not estimate these effects in this section.

[305] Comments of Allan L. Shampine, Ph.D. On "Competition and Consumer Protection in the 21st Century Hearings, Project Number P181201," August 20, 2018, p. 10.

199. The question of how to quantify the effect of reducing competition in a market arises commonly in the context of analyzing potential mergers. A merger is similar to an exclusion of a competitor in the sense that the number of independent competitors serving a market is lower if the merger is permitted than if the merger is precluded. To determine whether a merger is likely to have adverse effects on a market, economists have developed well-accepted methodologies for estimating the effect on prices of the elimination of a competitor.[306]

200. To evaluate the effects of eliminating a competitor from the market in a case of merger, economists and regulatory agencies often analyze market concentration.[307] The Herfindahl-Hirschman Index ("HHI") is an accepted measure of concentration.[308] The HHI is calculated by summing the squares of the individual firms' market shares.[309] The HHI ranges from close to zero for a market with a large number of small competitors, to 10,000 for a pure monopoly.

201. When market concentration significantly increases as a result of a merger (or exclusion of a competitor) and results in a highly concentrated market, such a merger raises concerns that the increased concentration will cause prices to increase significantly by increasing the market power of the remaining firms.[310]

202. The 2010 Horizontal Merger Guidelines classify markets into three types based on the value of the market's HHI:

- HHI below 1,500 – unconcentrated markets;

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[306] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3, 6-6.1; Carl Shapiro, "Mergers with Differentiated Products," *Antitrust*, Spring 1996, pp. 24-28, at http://faculty.haas.berkeley.edu/shapiro/diversion.pdf.

[307] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3. Market concertation evidence is considered in conjunction with other evidence of competitive effects, including ease and timeliness of potential entry into the market.

[308] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3.

[309] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3.

[310] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 2.1.3.

- HHI between 1,500 and 2,500 – moderately concentrated markets; and

- HHI above 2,500 – highly concentrated markets.[311]

203. According to the 2010 Horizontal Merger Guidelines, mergers resulting in highly concentrated markets and that increase the HHI by 100 to 200 points "potentially raise significant competitive concerns and often warrant scrutiny."[312] Mergers that result in highly concentrated markets and that increase the HHI by more than 200 points will be "presumed to be likely to enhance market power," unless proven otherwise.[313]

204. I calculated the HHIs in the market for all RAN equipment in each region. Exhibit IX.1 shows that the market for all RAN equipment is highly concentrated in each region, but more so in North America than in any other region. The high levels of concentration in North America reflected in Exhibit IX.1 are largely due to the limited presence of Huawei in the United States (discussed in Section VI).

[311] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3.
[312] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3.
[313] "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 5.3.

Exhibit IX.1
RAN Market Concentration by Region, 2018

Region	HHI	Number of Companies
North America	4,045	7
Europe	2,869	6
Middle East & Africa	3,187	5
Asia Pacific	2,568	9
Caribbean & Latin America	3,399	6

Notes:
[1] 5G RAN revenues are not available prior to Q4 2018.
[2] Dell'Oro Group discontinued data collection for CDMA RAN equipment in Q1 2019; data on CDMA RAN include only macro sites in Q2 2018-Q4 2018.
[3] GSM RAN sales include only sales of macro sites and base station controllers ("BSCs") in Q1 2019.

Sources:
[1] "TOTAL GSM," "TOTAL CDMA," "TOTAL WCDMA," "TOTAL LTE," "TOTAL 5G NR," Dell'Oro Group, Q1 2019.
[2] "Mobile RAN Quarterly Report: 1Q19," Dell'Oro Group, Tables 1, 2, and 3.

205. Estimating the effect of increased concentration (i.e., the increase in the HHI) in the United States because of Huawei's limited presence on prices for RAN equipment requires an estimate of vendors' RAN revenue shares assuming Huawei's participation is restricted in the market and an estimate of what vendors' RAN revenue shares would be if Huawei's presence were not restricted by government policies in the U.S. market.

206. Because Huawei has never been allowed to fully participate in the U.S. telecommunications equipment market, as I explained in Section VI, the observed revenue shares of Huawei and other vendors in North America are those in which Huawei is largely absent from the market. I use vendors' revenue shares in sales of all RAN equipment in North America in 2018 to approximate what their revenue shares would be assuming Huawei is restricted from the U.S. market.[314]

207. The revenue shares of Huawei and other vendors in the so-called "but for" world in which Huawei were allowed to fully participate in the U.S. market are not observed. I consider

[314] As I explained in Section VI, vendors' revenue shares in North America primarily reflect vendors' revenue shares in the U.S. This approach assumes that vendors' revenue shares across all generations of wireless RAN are a good approximation for their revenue shares for 5G RAN, both if Huawei were present or absent from the market.

three scenarios for what Huawei's revenue share would be if it were allowed to participate in the U.S. market: (1) Huawei's revenue share would equal its revenue share in Europe, (2) Huawei's revenue share would equal its average revenue share in all regions except North America, and (3) Huawei's revenue share would equal its average revenue share worldwide including the United States.[315]

208. I estimate other vendors' revenue shares in the presence of Huawei using so-called diversion ratios from these vendors to Huawei, which reflect the share of sales that would have been diverted from each vendor to Huawei were Huawei not excluded by policy in the United States[316] The assumed diversion ratio from vendor A to vendor B equals $s_B/(1-s_A)$, where s_A and s_B are revenue shares of vendors A and B, respectively.[317] The details of my analysis are provided in Appendix C.

209. Applying my estimates of revenue shares in the U.S. RAN market with and without Huawei, I estimate that the absence of Huawei from the U.S. market for RAN equipment increases the HHI from 2,964-3,125 to 4,071; i.e., the HHI increases by 945-1,106 points when Huawei is excluded. According to the 2010 Horizontal Merger Guidelines criteria

[315] These data are provided by Dell'Oro Group. Due to the confidentiality of these data, I am not able to provide Huawei's revenue shares in this report.

[316] Estimating diversion ratios from market shares is an approximation that may not be valid if subsets of products in the purported market form submarkets or otherwise are closer substitutes to one another than reflected by the market shares. In such circumstances it would be appropriate to conduct analyses of the cross-price elasticities between the products, data permitting, to obtain more accurate estimates of diversion ratios. In the instant case, however, there is no reason to believe that Huawei's products form a submarket with a subset of the products of the other vendors in the market. My methodology of considering three alternative sets of diversion ratios reflecting three different sets of market shares provides robustness to my estimated price effects. See Carl Shapiro, "Mergers with Differentiated Products," *Antitrust*, Spring 1996, p. 25, at http://faculty.haas.berkeley.edu/shapiro/diversion.pdf.

[317] Carl Shapiro, "Mergers with Differentiated Products," *Antitrust*, Spring 1996, p. 25, at http://faculty.haas.berkeley.edu/shapiro/diversion.pdf.

quoted above, such an increase in HHI would be presumed to enhance market power, cause prices to rise, and damage social welfare.[318]

Exhibit IX.2
Estimated Increase in Concentration in the U.S. Market for RAN Equipment if Huawei's Participation is Restricted in the U.S.

Concentration Estimate	Estimated Increase in Market Concentration if Huawei's Participation Is Restricted in the U.S. Market		
	Scenario 1	Scenario 2	Scenario 3
HHI without Huawei	4,071	4,071	4,071
HHI with Huawei	3,009	3,125	2,964
Increase in the HHI	1,061	945	1,106

Notes:
[1] Scenario 1 assumes that Huawei's revenue share in the U.S. market for RAN equipment if Huawei were allowed in the U.S. market would equal Huawei's revenue share in RAN equipment sales in Europe in 2018. Scenario 2 assumes that Huawei's revenue share in the U.S. market for RAN equipment if Huawei were allowed in the U.S. market would equal Huawei's revenue share in RAN equipment sales in all regions except North America in 2018. Scenario 3 assumes that Huawei's revenue share in the U.S. market for RAN equipment if Huawei were allowed in the U.S. market would equal Huawei's revenue share in RAN equipment sales worldwide in 2018.
[2] The Herfindahl-Hirschman Index ("HHI") in the presence of Huawei in the U.S. market for RAN equipment is calculated as follows: $HHI_H = (rs_{Huawei})^2 + (rs_{Ericsson})^2 + (rs_{Nokia})^2 + (rs_{Samsung})^2 + (rs_{ZTE})^2 + (rs_{Other})^2$, where rs_i denotes the revenue share of vendor *i* in the presence of Huawei in the U.S. market; and the HHI in the absence of Huawei from the U.S. market for RAN equipment is calculated as follows: $HHI_{WH} = (RS_{Ericsson})^2 + (RS_{Nokia})^2 + (RS_{Samsung})^2 + (RS_{ZTE})^2 + (RS_{Other})^2$, where RS_i denotes the revenue share of vendor *i* in the absence of Huawei from the U.S. market. For the purposes of this analysis, I aggregate all vendors except Huawei, Ericsson, Nokia, Samsung, and ZTE into "Other" category and use their aggregate revenue share to calculate the HHI.

Source: Exhibit C.1.

210. The effect on equipment prices of including Huawei in the market would not be isolated to the prices that Huawei itself would contribute to the market, but rather would affect all vendors' prices. In the absence of Huawei, the remaining firms face less pressure to reduce their prices in order to win business than they would face if competing not only with each

[318] Economist John Kwoka tested whether the criteria published in the 2010 Horizontal Merger Guidelines are in fact able to identify mergers that are anticompetitive. Using a sample of 42 merger retrospectives—detailed studies of the actual effects of past mergers on merger outcomes (mostly on prices)—he examined whether mergers that resulted in a highly concentrated market (HHI above 2,500), and where HHI increased by more than 200 points, resulted in price increases. He found that out of the 21 mergers in his sample that satisfy the 2,500/200 criteria, 18 (85.7 percent) resulted in price increases, and only three resulted in price decreases, leading to the conclusion that the 2010 Horizontal Merger Guidelines provide useful criteria for identifying anticompetitive effects. John Kwoka, "The Structural Presumption and the Safe Harbor in Merger Review: False Positives or Unwarranted Concerns?" *Antitrust Law Journal* 81, no. 3 (2017), p. 856-859.

other but also with Huawei.[319] Some of the sales that a vendor would otherwise lose to Huawei by increasing its price would instead remain with the vendor.[320] If the value of sales that would have been lost to Huawei had Huawei operated in the market is substantial, Huawei's absence from the market can result in substantial upward pricing pressure. Conversely, Huawei's presence in a market can generate substantial downward pricing pressure on all of the other competitors.

211. Economists have developed accepted methodologies for estimating the effect on prices that would result from this increased upward pricing pressure.[321] I have applied a methodology developed by an economist Carl Shapiro to estimate the effect on prices in the United States of excluding Huawei from U.S. sales of RAN equipment. This methodology allowed me to estimate the price increase using the data available to me. The results of my analysis of the effect on RAN equipment prices in the United States of excluding Huawei from the U.S. market are shown in Exhibit IX.3.

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[319] The regulatory agencies consider two types of competitive effects in merger reviews: (1) "coordinated effects" that arise if the merger makes it easier for the merged firm and its rivals to collude and (2) "unilateral effects" that arise if the merger would give the merged firm a unilateral incentive to raise prices and therefore harm consumers. Joseph Farrell and Carl Shapiro, "Antitrust Evaluation of Horizontal Mergers: An Economic Alternative to Market Definition," *The B.E. Journal of Theoretical Economics Policies and Perspectives* 10, iss. 1 (2010), p. 3. I estimate only unilateral effects of excluding Huawei from the market for RAN equipment. To the extent that there were coordinated effects because Huawei was banned from the U.S. market, my analysis would be conservative by not including them.

[310] The regulatory agencies consider two types of competitive effects in merger reviews: (1) "coordinated effects" that arise if the merger makes it easier for the merged firm and its rivals to collude and (2) "unilateral effects" that arise if the merger would give the merged firm a unilateral incentive to raise prices and therefore harm consumers. Joseph Farrell and Carl Shapiro, "Antitrust Evaluation of Horizontal Mergers: An Economic Alternative to Market Definition," *The B.E. Journal of Theoretical Economics Policies and Perspectives* 10, iss. 1 (2010), p. 3. I estimate only the unilateral effects of excluding Huawei from the market for RAN equipment in my analysis. To the extent that there were coordinated effects because Huawei was banned from the U.S. market, my analysis would be conservative by not including them.

[321] See the discussion of several available methodologies for the estimation of the price increases resulting from a merger in Carl Shapiro, "Mergers with Differentiated Products," *Antitrust*, Spring 1996, pp. 24-28, at http://faculty.haas.berkeley.edu/shapiro/diversion.pdf; "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 6.1.

Exhibit IX.3
Estimated Price Increases of RAN Equipment Resulting from Restricting Huawei's Participation the U.S. Market

Vendors	Estimated Increase in Price if Huawei's Participation Is Restricted in the U.S. Market		
	Scenario 1	Scenario 2	Scenario 3
[A]	[B]	[C]	[D]
ERICSSON	16.4%	18.4%	14.6%
NOKIA	14.0%	15.8%	12.5%
SAMSUNG	6.3%	7.3%	5.5%
ZTE	5.6%	6.4%	4.8%
OTHER	5.7%	6.5%	4.9%
Weighted Average Price Increase (%)	**14.2%**	**16.0%**	**12.6%**

Notes:
[1] Scenario 1 assumes that Huawei's revenue share in the U.S. market for RAN equipment if Huawei were allowed in the U.S. market would equal Huawei's revenue share in RAN equipment sales in Europe in 2018. Scenario 2 assumes that Huawei's revenue share in the U.S. market for RAN equipment if Huawei were allowed in the U.S. market would equal Huawei's revenue share in RAN equipment sales in all regions except North America in 2018. Scenario 3 assumes that Huawei's revenue share in the U.S. market for RAN equipment if Huawei were allowed in the U.S. market would equal Huawei's revenue share in RAN equipment sales worldwide in 2018.
[2] The weighted average price increase is calculated as follows:
$pi_{Ericsson}*rs_{Ericsson}+pi_{Nokia}*rs_{Nokia}+pi_{Samsung}*rs_{Samsung}+pi_{ZTE}*rs_{ZTE}+pi_{Other}*rs_{Other}$, where pi_i is the estimated price increase of vendor *i* and rs_i is the revenue share of vendor *i* in the absence of Huawei in the market; *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other. For the purposes of this analysis, I aggregate all vendors except Huawei, Ericsson, Nokia, Samsung, and ZTE into "Other" category.

Source: Exhibit C.1.

212. As the exhibit shows, I estimate that in the absence of Huawei from the market, the prices of smaller vendors (Samsung, ZTE, and other vendors[322]) are 4.8-7.3 percent higher than they would be in Huawei's presence; Nokia's prices are higher by 12.5-15.8 percent; and Ericsson's prices are higher by 14.6-18.4 percent.

213. I estimate that, overall, the increased market concentration resulting from the absence of Huawei from the U.S. market for RAN equipment has resulted in and will continue to result in 12.6-16.0 percent higher weighted average prices for RAN equipment than would be observed in the market if Huawei were competing in the United States.

[322] "Other vendors" means vendors other than Huawei, Ericsson, Nokia, Samsung, and ZTE.

214. An increase of prices of 12.6-16.0 percent is considered material and harmful to social welfare.[323] First, because these price increases constitute a cost increase experienced by wireless carriers, they would discourage and delay deployment of 5G networks.

215. In addition, higher prices for RAN equipment would discourage the upgrade of networks at all for marginal locations where the profitability of network upgrades would be close to zero even at more competitive prices. These locations would include areas where network costs may be higher and/or demand per square mile lower. According to the FCC, such areas often include rural areas, where customers are often underserved by newer technologies. The FCC attributes, at least partially, the lack of advanced broadband networks available to Americans living in rural areas and on Tribal lands to the cost of infrastructure build out:

> The existence of these unserved areas may be attributable, at least partially, to the cost of building infrastructure over long distances in areas with low population density, as well as the lower incomes and higher rates of poverty and unemployment in rural versus urban areas. This translates into fewer revenue generating opportunities for service providers and ultimately affects their incentive to build broadband networks. [footnote omitted][324]

216. As a result, higher costs for 5G equipment may disproportionately harm areas where, by U.S. policy, there is a particular public interest in encouraging deployment of new wireless technology.

217. In addition, cost increases experienced by wireless carriers would be expected to affect the prices that consumers, businesses, and governments pay for wireless services. While it is

[323] For example, the 2010 Horizontal Merger Guidelines consider 5 percent a commonly used benchmark to assess a price increase that is commensurate with a significant lessening in competition. See "Horizontal Merger Guidelines," U.S. Department of Justice and the Federal Trade Commission, August 19, 2010, Sec. 4.1.1-4.1.2. Kwoka concludes that a price increase of 5.8 percent (and perhaps less) is harmful to social welfare. John Kwoka, "The Structural Presumption and the Safe Harbor in Merger Review: False Positives or Unwarranted Concerns?" *Antitrust Law Journal* 81, no. 3 (2017), p. 856.

[324] 2015 Broadband Progress Report and Notice of Inquiry on Immediate Action to Accelerate Deployment, *In the Matter of Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act*, Before the Federal Communications Commission, GN Docket No. 14-126, FCC 15-10 (Released: February 4, 2015), ¶¶ 133, 143.

beyond the scope of this report to estimate the degree to which wireless carriers would pass through their cost increases to consumers, economic theory tells us that it is reasonable to expect at least some of the cost increase to be passed through in the form of higher end-user prices.

218. Finally, the lessening of competition can also affect the quality of products offered in the U.S. market and the amount of innovation that U.S. consumers enjoy. The competitive effect of higher market concentration due to Huawei's absence from the U.S. RAN market is, therefore, unlikely to be limited only to higher prices of products offered in the United States. For example, without direct competition from Huawei in the United States, Ericsson and Nokia would rationally find it somewhat less pressing to intensify their R&D expenditures and accelerate their R&D efforts to develop better, more convenient, or more innovative products. They would especially find it less pressing to intensify their efforts to focus their R&D on the technological needs of the U.S. market specifically, deriving from the spectrum profile in the U.S. as well as its geography, demographics, and other characteristics. None of my analyses have quantified the cost to consumers of inferior network performance or depressed innovation that would be expected from excluding from the market the vendor that is the most technologically accomplished and that constitutes the most challenging technological competitor to the other vendors serving the United States.

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Dr. Debra J. Aron is a Vice President in the Competition Practice. Debra applies her expertise in economic and policy matters, including competition and antitrust analysis, intellectual property, class certification, and damages analysis, in both regulatory and litigation disputes. She has provided expert testimony for over 20 years in a variety of high-stakes federal, state, regulatory, and arbitration cases relating to competition and antitrust including market definition, conduct cases, and price fixing damages, intellectual property damages including patents and trade secrets; class actions and class certification including consumer fraud matters and TCPA; pricing; unjust enrichment; and economic cost analyses. She also has conducted competition analyses in several high-profile mergers and macroeconomic analyses of pricing and investment changes. Dr. Aron's practice spans many industries, and she has a specific expertise in telecommunications and technology, including wireless services, wireline services, backbone, RAN, and customer premises equipment, satellite communications, and computer technology.

Publications

"Lessons from the Economic Deregulation of the Airline and Telecommunications Industries.," *Infrastructure* 58, no. 2 (Winter 2019).

"An Empirical Analysis of Regulator Mandates on the Pass Through of Switched Access Fees for In-State Long-Distance Telecommunications in the U.S.," with David E. Burnstein, Ana Danies, and Gerry Keith, June 19, 2013. Available at SSRN: http://ssrn.com/abstract=1674082.

Contributing author, ABA SECTION OF ANTITRUST LAW, TELECOM ANTITRUST HANDBOOK, Second Edition, (Chicago: American Bar Association), March 2013.

"The Effects of Legacy Pricing Regulation on Adoption of Broadband Service in the United States," with Allan T. Ingraham, *Review of Network Economics* 11, issue 4, 2012.

"Social Welfare Implications of Liability Rules in Major Environmental Damages Cases," with Francis X. Pampush, Environmental Litigation Committee Newsletter, Fall 2011.

"Regulatory Policy and the Reverse Cellophane Fallacy," with David E. Burnstein, *Journal of Competition Law and Economics* 2010; doi: 10.1093/joclec/nhp033.

"Investment in Next Generation Networks and Wholesale Telecommunications Regulation," with Robert W. Crandall, November 3, 2008. Available at SSRN: http://ssrn.com/abstract=1294910.

"Pricing Principles and Pricing Methodologies for Essential Facilities," May 2008.

Contributing author, ABA SECTION OF ANTITRUST LAW, TELECOM ANTITRUST HANDBOOK, (2005), (Chicago: American Bar Association), 2005.

"The Proper Treatment of Spare Network Capacity in Regulatory Cost Models," with Ana Danies, May 2005. Available at SSRN http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2133365.

"State Commissions Systematically Have Set UNE Prices Below Their Actual Costs," with Frank Pampush and E. Gerry Keith, November 2003. Available at SSRN http://ssrn.com/abstract=3327613.

"Broadband Adoption in the United States: An Empirical Analysis," with David E. Burnstein, in DOWN TO THE WIRE: STUDIES IN THE DIFFUSION AND REGULATION OF TELECOMMUNICATIONS TECHNOLOGIES, Allan Shampine, ed., (Nova Science Publishers, Hauppauge, NY, 2003).

"Developments in the Theory of Vertical Foreclosure as Applied to Regulated Telecommunications Markets" (March 2002), Prepared for Presentation at The American Bar Association Section of Antitrust Law, 50th Annual Spring Meeting.

"Modifications at HHIs for Vertical Supply Relationships" with Wenqing Li and James Langenfeld, White Paper submitted to European Commission, February 2000.

"Economic Theories of Tying and Foreclosure Applied—And Not Applied—in Microsoft," with Steven S. Wildman, *Antitrust* 14, no. 1, 1999, pp.48-52.

"Effecting a Price Squeeze Through Bundled Pricing," with Steven S. Wildman, in COMPETITION, REGULATION, AND CONVERGENCE: CURRENT TRENDS IN TELECOMMUNICATIONS POLICY RESEARCH, Gillett and Vogelsang, eds. (New Jersey: Lawrence Erlbaum Associates, Inc.) 1999, pp. 1-17.

"Worldwide Wait? How the Telecom Act's Unbundling Requirements Slow the Development of the Network Infrastructure," with Ken Dunmore and Frank Pampush, *Industrial and Corporate Change* 7, no. 4, 1998, pp. 615-621.

"The Pricing of Customer Access in Telecommunications," with Steven S. Wildman, *Industrial and Corporate Change* 5, no. 4, 1996, pp. 1029-1047.

"Bonus and Penalty Schemes as Equilibrium Incentive Devices, With Application to Manufacturing Systems," with Pau Olivella, *Journal of Law, Economics, and Organization* 10, Spring 1994, pp. 1-34.

"Diversification as a Strategic Preemptive Weapon," *Journal of Economics and Management Strategy* 2, Spring 1993, pp. 41-70.

"Using the Capital Market as a Monitor: Corporate Spin-offs in an Agency Framework," *RAND Journal of Economics* 22, Winter 1991, pp. 505-518.

"Firm Organization and the Economic Approach to Personnel Management, *American Economic Review* 80, no. 2, May 1990, pp. 23-27.

“The Introduction of New Products,” with Edward P. Lazear, *American Economic Review* 80, no. 2, May 1990, pp. 421-426.

“Ability, Moral Hazard, Firm Size, and Diversification,” *RAND Journal of Economics* 19, Spring 1988, pp. 72-87.

“Worker Reputation and Productivity Incentives,” *Journal of Labor Economics* 5, no. 4, October 1987, part 2, pp. S87-S106.

“The Role of Managerial Ability and Moral Hazard in the Determination of Firm Size, Growth and Diversification,” Ph.D. Dissertation, University of Chicago, August 1985.

Presentations

“Balancing Unquantified Benefits and Harms Under the Consumer Welfare Standard,” The New York State Bar Association Antitrust Law Section, 2019 William Howard Taft Lecture, Commenter to the remarks of The Honorable Douglas H. Ginsburg, New York, New York, September 2019.

“The Impact on the U.S. Economy of Excluding Huawei from Participation in the U.S. Market for Wireless Network Equipment,” Presentation at the Fiscal Year 2019 National Defense Authorization Act, Section 889, Public Meeting of Department of Defense, General Services Administration, and NASA, Washington DC, July 19, 2019.

Moderator, “Your Expert Is Your Friend: How to Effectively Deliver Expert Testimony,” ABA: The Woman Advocate Committee Regional CLE Program: Raising the Bar, Chicago, IL, October 2018.

“Lessons from the Deregulation of the Airline and Telecommunications Industries,” ABA Infrastructure and Regulated Industries Section, Dallas, Texas, August 2018.

“Economic Fundamentals: Vertical and Coordinated Effects in Mergers,” ABA Section of Antitrust Law, Fundamentals of Antitrust Economics Series, Chicago, Illinois, July 2018.

Panelist, “Considerations for the Economists’ Analysis in Opt-Out Relative to Class Action Litigation,” ABA 5th Annual Western Regional CLE Program on Class Actions and Mass Torts, San Francisco, California, June 2018.

“Lessons from the Deregulation of the Airline and Telecommunications Industries,” ABA Infrastructure and Regulated Industries Section, Fall Council Meeting, Palm Beach, Florida, October 2017.

“Economic Fundamentals: Vertical and Coordinated Effects in Mergers,” ABA Section of Antitrust Law, Fundamentals of Antitrust Economics Series, Washington D.C., May 2016.

Panelist, “Economic Fundamentals: Market Power,” ABA Spring Meeting, Washington D.C., April 2016.

“The Economic Impact of Electricity Price Increases in Puerto Rico,” ABA Section of Public Utility, Communications and Transportation Law, Spring Council Meeting, Naples, FL, March 2016.

Moderator, “Effective Cross-Examination of the Expert Witness: Practical Tips and Video Clips,” ABA Annual Meeting, Chicago, July 2015.

Moderator, “The Science of Persuasion: Practical Insights from Research on Expert Witness Effectiveness and Jury Decision-Making,” ABA Section of Litigation Annual Conference, New Orleans, April 2015.

Panelist, “How to Manage Conversations with Expert Witnesses,” ABA Section of Litigation, Environmental, Mass Torts, & Products Liability Litigation Committees’ Joint CLE Seminar, Avon, Colorado, January 30, 2014.

“The Effects of Legacy Pricing Regulation on Adoption of Broadband Service in the United States,” Federal Communications Commission, Washington, D.C., June 11, 2013.

Panelist, “A Primer: Getting the Most Out of Your Experts — Do’s and Don’ts in the Use of Expert Witnesses: Learning from the Experts,” ABA Section of Litigation Annual Conference, Chicago, Illinois, April 26, 2013.

“An Empirical Analysis of Regulator Mandates on the Pass Through of Switched Access Fees for In-State Long-Distance Telecommunications in the U.S.,” with David E. Burnstein, Ana Danies, and Gerry Keith, Wesleyan University, Middletown, Connecticut, March 27, 2013.

“The Effects of Legacy Pricing Regulation on Adoption of Broadband Service in the United States,” with Allan Ingraham, The 40th Research Conference on Communication, Information and Internet Policy (TPRC), September 22, 2012.

Panelist, “Two Decades of Daubert: Junk Science Replaced by Junk Rulings?” ABA Section of Litigation Annual Conference, Washington, DC, April 20, 2012.

“The Effects of Legacy Pricing Regulation on Adoption of Broadband Service in the United States,” with Allan Ingraham, New America Foundation, workshop on Defining and Measuring Meaningful Broadband Adoption, April 11, 2012, Washington, DC.

“Social Welfare Implications of Liability Rules in Major Environmental Damages Cases,” with Francis X. Pampush, American Bar Association Sections of Litigation and Criminal Justice Joint Annual Conference, April 15, 2011, Miami, Florida.

“Consumer Benefits of Intrastate Access Rate Reform in Minnesota,” Center for Science, Technology and Public Policy, Humphrey School of Public Affairs, University of Minnesota, January 26, 2011.

“An Empirical Analysis of Regulator Mandates on the Pass Through of Switched Access Fees for In-State Long-Distance Telecommunications in the U.S.,” with David E. Burnstein, Ana Danies, and Gerry Keith, The 38th Research Conference on Communication, Information and Internet Policy

Telecommunications Policy Research Conference), October 3, 2010, George Mason University Law School, Arlington, Virginia.

“Pricing Principles and Pricing Methodologies for Essential Facilities,” The 36th Research Conference on Communication, Information and Internet Policy (TPRC), September 27, 2008.

“Regulatory Policy and the Reverse Cellophane Fallacy,” with David E. Burnstein, 17th Biennial International Telecommunications Society Conference, Montréal, Québec, Canada, June 24-27, 2008.

“The Use of Economic Analysis in ‘Industry Expert’ Testimony,” CLE course, XPRT Forum, March 7, 2008.

Presentations to the New Jersey Board of Public Utilities and to the New Jersey Legislature’s Telecommunications Utilities Committee regarding the economic principles for a forward-looking regulatory agenda in light of the facts of competition nationwide and in New Jersey, and the costs of regulation, October – November 2006.

“The Interaction of Regulation with Economics and Financial Analysis in Litigation, Policy, and Strategy Consulting,” CLE course, XPRT Forum, October 7, 2006.

“Comments on ‘Economic Analysis in FCC Merger Proceedings,’” Conference on Economic Analysis and FCC Decisionmaking, presented by the Federal Communications Bar Association (FCBA) and Stanford Institute for Economic Policy Research (SIEPR), Washington D.C., March 15, 2006.

“Economic Principles for Consumer Protection Rules,” Pri Telecom / Tech Briefing, Santa Clara, California, October 11, 2005.

“The Proper Treatment of Spare Network Capacity in Regulatory Cost Models,” Presentation at the Advanced Workshop in Regulation and Competition, Center for Research in Regulated Industries, Skytop, Pennsylvania, May 2005.

“Telecommunications Regulation: What’s Obsolete? What Will Become Obsolete?” Presentation at the State and City Telecom Reform Conference, Heartland Institute, Chicago, Illinois, December 2004.

“Trends in Telecommunications Demand & Supply,” Presentation at the 46th Annual NARUC Regulatory Studies Program, Michigan State University, August 2004.

“The Economic Costs of Proposed Wireless Regulations in California,” Presentation to Commissioners Brown and Kennedy, California Public Utilities Commission, San Francisco, California, April 2004.

“The Economics of UNE Pricing: Presentation to Staff,” Ex parte presentation to the staff of the FCC, in FCC WC Docket No. 03-173: Review of the Commission’s Rules Regarding the Pricing of Unbundled Network Elements and the Resale of Service by Incumbent Local Exchange Carriers, March 2004.Unbundled Network Elements and the Resale of Service by Incumbent Local Exchange Carriers, March 2004.

“The High Cost of Proposed New Wireless Regulations,” Presentation to the Pacific Research Institute conference “Regulating Wireless in California: Bill of Rights... or Wrongs?,” San Francisco, April 2003.

“The TELRIC Showdown,” Panelist, NARUC Staff Subcommittee on Telecommunications, 2002 Annual Convention, Chicago, Illinois, November 2002.

“Economic Principles for Efficient Pricing of Municipal Rights-of-Way,” National Association of Telecommunications Officers and Advisors (NATOA), Chicago, Illinois, September 2002.

“Trends in Voice and Broadband Competition in Telecommunications Markets: Markets, Strategies, and Regulation,” 82nd Annual Convention of the Indiana Telecommunications Association, Lexington, Kentucky, June 2002.

“Broadband Deployment in the United States,” Emerging Opportunities in Broadband Symposium, Northwestern University, Evanston, Illinois, December 2001.

“Local Competition in Illinois,” Illinois Telecommunications Symposium, Northwestern University, Evanston, Illinois, December 2000.

“Licensing and Access to Innovations in Telecommunications and Information Services,” Telecommunications Policy Research Conference, Alexandria, Virginia, September 2000.

“Effecting a Price Squeeze Through Bundled Pricing,” Federal Communications Commission, Washington, D.C., May 1999.

“Competitive and Strategic Use of Optional Calling Plans and Volume Pricing Plans,” The Institute for International Research Conference for Competitive Pricing of Telecommunications Services, Chicago, Illinois, July 1998.

“Effecting a Price Squeeze Through Bundled Pricing,” Consortium for Research in Telecommunications Policy Conference, University of Michigan, Ann Arbor, Michigan, June 1998.

“The Pricing of Customer Access in Telecommunications,” Conference on Public Policy and Corporate Strategy for the Information Economy, Evanston, Illinois, May 1996.

“Diversification as a Strategic Preemptive Weapon,” University of Iowa, Iowa City, Iowa, February 1994.

"Diversification as a Strategic Preemptive Weapon, "University of Buffalo, Buffalo, New York, February 1994.

"Diversification as a Strategic Preemptive Weapon," University of Southern California, Los Angeles, California, December 1993.

"Strategic Pricing," Winter Meetings of the Econometric Society, Discussant, Anaheim, California, December 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," Michigan State University, Lansing, Michigan, November 1993.

"Diversification as a Strategic Preemptive Weapon," Rutgers University, New Brunswick, New Jersey, November 1993.

"Diversification as a Strategic Preemptive Weapon," University of California at Santa Cruz, Santa Cruz, California, November 1993.

"Diversification as a Strategic Preemptive Weapon," Graduate School of Business, Stanford University, Stanford, California, November 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," Purdue University, West Lafayette, Indiana, September 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," Summer Meetings of the Econometric Society, Boston University, Boston, Massachusetts, June 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," University of California, Department of Economics, Berkeley, California, May 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," Stanford University, Graduate School of Business, Stanford, California, May 1993.

"Diversification as a Strategic Preemptive Weapon," Stanford University, Graduate School of Business, Stanford, California, April 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," Hoover Institution, Stanford, California, April 1993.

"Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets," University of California, Graduate School of Business, Berkeley, California, February 1993.

“Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets,” Stanford University, Department of Economics, Stanford, California, February 1993.

“Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets,” Hoover Institution, Stanford, California, January 1993.

“Pricing Strategies,” Session Discussant, 1992 North American Winter Meeting of The Econometric Society, Anaheim, California, January 1992.

“Diversification as a Strategic Preemptive Weapon,” University of Toronto, Toronto, Canada, November 1991.

“Diversification as a Strategic Preemptive Weapon,” Queen’s University, Kingston, Ontario, Canada, November 1991.

“Bonuses and Penalties as Equilibrium Incentive Devices, with Application to Manufacturing Systems,” University of Chicago, Chicago, Illinois, June 1991.

“The Timing of Entry into New Markets,” Summer Meetings of the Econometric Society, University of Pennsylvania, Philadelphia, Pennsylvania, June 1991.

“Innovation, Imitation, Productive Differentiation, and the Value of Information in New Markets,” University of Chicago, Chicago, Illinois, April 1991.

“Bonuses and Penalties as Equilibrium Incentive Devices, with Application to Manufacturing Systems,” Winter Meetings of the Econometric Society, Washington, D.C., December 1990.

“Corporate Spin-offs in an Agency Framework,” University of Washington, Seattle, Washington, October 1990.

“The Timing of Entry Into New Markets,” University of British Columbia, Vancouver, British Columbia, October 1990.

“Corporate Spin-offs in an Agency Framework,” Texas A&M University, College Station, Texas, April 1990.

“Firm Organization and the Economic Approach to Personnel Management,” Winter Meetings of the American Economic Association, New York, New York, December 1989.

"Corporate Spin-offs in an Agency Framework," Western Finance Association Meetings, Seattle, Washington, June 1989.

"Corporate Spin-offs in an Agency Framework," University of Rochester, Rochester, New York, May 1989.

"Corporate Spin-offs in an Agency Framework," North American Summer Meetings of the Econometric Society, Minneapolis, Minnesota, June 1988.

"Competition, Relativism, and Market Choice," North American Summer Meetings of the Econometric Society, Berkeley, California, June 1987.

"Competition, Relativism, and Market Choice," University of Chicago, Chicago, Illinois, April 1987.

"Rate Reform and Competition in Electric Power," Discussant, Conference on Competitive Issues in Electric Power, Northwestern University, Evanston, Illinois, March 1987.

"Worker Reputation and Productivity Incentives," New Economics of Personnel Conference, Arizona State University, Tempe, Arizona, April 1986.

"Ability, Moral Hazard, and Firm Diversification," Various Universities, 1985, 1994, including Yale University, University of Rochester, Stanford University, University of Minnesota, California Institute of Technology, Duke University, Northwestern University, Brown University, Harvard University, University of California - Los Angeles, University of Pennsylvania.

Academic Journal Refereeing

Dr. Aron has served as a referee for The Rand Journal of Economics, the Journal of Political Economy, the Journal of Finance, the American Economic Review, the Quarterly Journal of Economics, the Journal of Industrial Economics, the Journal of Economics and Business, the Journal of Economic Theory, the Journal of Labor Economics, the Review of Industrial Organization, the European Economic Review, the Journal of Economics and Management Strategy, the International Review of Economics and Business, the Quarterly Review of Economics and Business, Management Science, the Journal of Public Economics, the Journal of Institutional and Theoretical Economics, and the National Science Foundation.

Testimony (2011-2019)

Deposition of Debra J. Aron in Motorola Solutions, Inc. et al. v. Hytera Communications Corporation Ltd. et al., United States District Court, for the Northern District of Illinois, Eastern Division, Case No. 1:17-cv-01973, September 20, 2019.

Deposition of Debra J. Aron in Jonathan Coffey et al. v. WCW & Air, Inc. et al., United States District Court, for the Northern District of Florida, Pensacola Division, Case No. 3:17-cv-90-TKW-HTC, September 13, 2019.

Deposition of Debra J. Aron in Sumotext Corp. v. Zoove, Inc. et al., United States District Court, Northern District of California, San Jose Division, Case No. 5:16-cv-01370-BLF-NMCx, August 1, 2019.

Deposition of Debra J. Aron in Waddell Williams, et al. v. Bluestem Brands, Inc., United States District Court, Middle District of Florida, Tampa Division, Case No. 8:17-CV-1971-T-27AAS, September 21, 2018.

Deposition of Debra J. Aron in Robert Hossfeld, et al. v. Compass Bank, N.A., et al., United States District Court, Northern District of Alabama, Southern Division, Case No. 2:16-CV-2017-ACA, September 7, 2018.

Deposition of Debra J. Aron in Ventures Edge legal, PLLC, et al. v. GoDaddy.com, LLC, et al., United States District Court, District of Arizona, Case No. 2:15-cv-02291-GMS, January 30, 2018.

Deposition of Debra J. Aron in Rajesh Verma, et al. v. Memorial Healthcare Group Inc., et al., United States District Court, Middle District of Florida, Jacksonville Division, Case No. 3:16-CV-00427-HLA-JRK, June 27, 2017.

Trial Testimony of Debra J. Aron in T-Mobile USA, Inc. v. Huawei Device, USA, Inc., et al., In the United States District Court for the Western District of Washington at Seattle, Case No. C14-1351-RAJ, May 12, 2017.

Deposition of Debra J. Aron in Re Optical Disk Drive Antitrust Litigation, Hewlett-Packard Company v. Toshiba Corp., et al., United States District Court, Northern District of California, MDL Docket No. 3:10-MD-02143-RS, Case No. 3:13-cv-05370-RS, March 23, 2017.

Deposition of Debra J. Aron in Peerless Network, Inc., et al. v. AT&T Corp., In the United States District Court for the Southern District of New York, Case No. 15 CV 870, February 17, 2017.

Trial Testimony of Debra J. Aron in Thomas H. Krakauer, et al. v. Dish Network, L.L.C., In the United States District Court for the Middle District of North Carolina, Durham Division, Case No.

1:14-CV-333, January 17, 2017.

Deposition of Debra J. Aron in T-Mobile USA, Inc. v. Huawei Device, USA, Inc., et al., In the United States District Court for the Western District of Washington at Seattle, Case No. C14-1351-RAJ, September 29, 2016.

Deposition of Debra J. Aron in Southwestern Bell Telephone Co., et al. v. V247 Telecom, LLC, et al., In the United States District Court for the Northern District of Texas, Dallas Division, Case No. 3:14-CV-01409-M, August 31, 2016.

Hearing Testimony of Dr. Debra J. Aron in Order Instituting Investigation into the State of Competition Among Telecommunications Providers in California, and to Consider and Resolve Questions raised in the Limited Rehearing of Decision 08-09-042, Before the Public Utilities Commission of the State of California, Investigation 15-11-007, July 20, 2016.

Prefiled Written Rebuttal Testimony of Dr. Debra J. Aron in Order Instituting Investigation into the State of Competition Among Telecommunications Providers in California, and to Consider and Resolve Questions raised in the Limited Rehearing of Decision 08-09-042, Before the Public Utilities Commission of the State of California, Investigation 15-11-007, July 15, 2016.

Prefiled Written Testimony of Dr. Debra J. Aron in Order Instituting Investigation into the State of Competition Among Telecommunications Providers in California, and to Consider and Resolve Questions raised in the Limited Rehearing of Decision 08-09-042, Before the Public Utilities Commission of the State of California, Investigation 15-11-007, June 1, 2016 and March 5, 2016.

Deposition of Debra J. Aron in Ramzy Ayyad, et al. v. Sprint Spectrum, L.P., In the Superior Court of the State of California for the County of Alameda, Case No.: RG03-121510, March 29, 2016.

Deposition of Debra J. Aron in Avnet, Inc. and BSP Software, LLC v. Motio, Inc., In the United States District Court for the Northern District of Illinois, Eastern Division, Case No.: 1:12-cv-2100, March 9, 2016.

Deposition of Debra J. Aron in Lena K. Thodos and David Miller, et al. v. Nicor, Inc., et al., In the Circuit Court of Cook County, Illinois County Department, Chancery Division, Case No.: 1:12-cv-2100, February 22, 2016.

Deposition of Debra J. Aron in Henry Espejo v. Santander Consumer USA, Inc., In the United States District Court for the Northern District of Illinois, Eastern Division, Case No.: 1:11-cv-08987, January 12, 2016.

Deposition of Debra J. Aron in Rachel Johnson, et al., v. Yahoo!, Inc. and Zenaida Calderin, et al. v. Yahoo!, Inc., in the United States District Court for the Northern District of Illinois, Eastern Division, Case Nos.: 14-cv-2028 and 14-cv-2753 and Rafael David Sherman, et al., v. Yahoo!, Inc., In the United States District Court for the Southern District of California, Case No.: 13-CV-00041-GPC-WVG (Combined), June 23, 2015.

Trial Testimony of Debra J. Aron in Salsgiver Communications, Inc., et al., v. Consolidated Communications Holdings, Inc., et al., In the Court of Common Pleas, Allegheny County, Pennsylvania, Case No. No. GD 08-7616, May 2015.Communications Holdings, Inc., et al., In the Court of Common Pleas, Allegheny County, Pennsylvania, Case No. No. GD 08-7616, May 2015.

Deposition of Debra J. Aron in Herbert Chen et al. v. Robert Howard-Anderson et al., In the Court of Chancery of the State of Delaware, Case No. C.A. 5878-VCL, December 16, 2014.

Deposition of Debra J. Aron in Sprint Communications Company L.P. v. Comcast Cable Communications, LLC, et al., In the United States District Court for the District of Delaware, Case No. 1:12-cv-01013-RGA, November 20, 2014.

Testimony of Debra J. Aron in Bayer CropScience LP v. Albaugh, Inc., et al., Before the American Arbitration Association, Case No. 16-171-Y-00511-12, October 20-21, 2014.

Trial Testimony of Debra J. Aron in Comcast IP Holdings I, LLC v. Sprint Communications Company L.P., et al., In the United States District Court for the District of Delaware, Case No. 12-205-RGA (CJB), October 9, 2014.

Prefiled Written Reply Testimony of Debra J. Aron in The Utility Reform Network v. Pacific Bell Telephone Company, Before the Public Utilities Commission of the State of California, Case No. 13-12-005, October 3, 2014.

Deposition of Debra J. Aron in Amanda Balschmiter, et al., v. TD Auto Finance, LLC, In the United States District Court, Northern District of Illinois, Eastern Division, Case No. 13cv1186, September 10, 2014.

Prefiled Written Testimony of Debra J. Aron in The Utility Reform Network v. Pacific Bell Telephone Company, Before the Public Utilities Commission of the State of California, Case No. 13-12-005, August 22, 2014.

Deposition of Debra J. Aron in Grant Birchmeier, et al., v. Caribbean Cruise Line, Inc., et al., In the United States District Court, Northern District of Illinois, Eastern Division, Case No. 12 CV 4069, July 19, 2014.

Deposition of Debra J. Aron in Comcast IP Holdings I, LLC v. Sprint Communications Company L.P., et al., United States District Court for the District of Delaware, Case No. 12-205-RGA(CJB), July 11, 2014.

Deposition of Debra J. Aron in In re: Methyl Tertiary Butyl Ether Products Liability Litigation, Commonwealth of Puerto Rico, et al., v. Shell Oil Co., et al., In the United States District Court, Southern District of New York, Case No. 07 Civ. 10470, May 27, 2014.

Depositions of Debra J. Aron in In re: Polyurethane Foam Antitrust Litigation, General Motors, L.L.C. v. Carpenter Co., et al., In the United States District Court for the Northern District of Ohio, Western Division, Case No. 3:12-pf-10027-JZ, April 30, 2014 and September 8, 2014.

Trial Testimony of Debra J. Aron in Seth Warnick, et al., v. Dish Network, L.L.C., In the United States District Court, District of Colorado, Civil Action No. 12-cv-01952-WYD, March 20, 2014.

Deposition of Debra J. Aron in Seth Warnick, et al., v. Dish Network, L.L.C., In the United States District Court, District of Colorado, Civil Action No. 12-cv-01952-WYD, September 25, 2013.

Deposition of Debra J. Aron in In re: Methyl Tertiary Butyl Ether (“MTBE”) Product Liability Litigation, New Jersey Department of Environmental Protection, et al. v. Atlantic Richfield Co., et al., In the United States District Court, Southern District of New York, No. 08 Civ. 312, May 29, 2013.

Prefiled Written Testimony and Reply Testimony of Debra J. Aron in In the Matter of the Petition Filed by ALASCOM, INC. d/b/a AT&T ALASKA to be Relieved of its Carrier of Last Resort Responsibilities in Certain Locations in Southwest Alaska, Before the Regulatory Commission of Alaska, Docket No. U-12-127, April 1, 2013 and January 17, 2013.

Deposition of Debra J. Aron in William Douglas Fulghum, et al., v. Embarq Corporation, et al., In the United States District Court for the District of Kansas, Civil Action No.: 07-CV-2602 (EFM/JPO), November 29, 2011.

Deposition of Debra J. Aron in Southwestern Bell Telephone Company, et al., v. IDT Telecom, Inc., et al., In the United States District Court, Northern District of Texas, Dallas Division, Civil Action No. 3-09-CV-1268-P, November 10, 2011.

Direct and Rebuttal Testimony of Debra J. Aron in the Matter of Petition of Sprint to Reduce Intrastate Switched Access Rates of Incumbent Local Exchange Carriers in North Carolina, Before the North Carolina Utilities Commission, Docket No. P-100, Sub 167, August 18, 2011 and September 27, 2011.

Prefiled Written Testimony and Rebuttal Testimony of Debra J. Aron in the Matter of: An Investigation Into the Intrastate Switched Access Rates of All Kentucky Incumbent and Competitive Local Exchange Carriers, Commonwealth of Kentucky, Before the Public Service Commission, Docket No. 2010-00398, September 30, 2011, and July 8, 2011.

Testimony of Debra J. Aron before the Utilities Committee of the Kansas Legislature regarding the status of competition in telecommunications markets in Kansas, February 2011.

Testimony of Debra J. Aron before the Telecommunications Committee of the Legislature of the state of Washington regarding the consumer benefits and competitive effects of switched access reform, February 2011.

Professional organizations

Member, American Economic Association

Member, Econometric Society

Associate Member, American Bar Association

Past Member, Telecommunications Policy Research Conference Program Committee

Honors and awards

Guthman Research Chair, Kellogg Graduate School of Management, Northwestern University, Summer 1994.

Hoover National Fellowship, Hoover Institution, 1992-1993.

Faculty Research Fellow, National Bureau of Economic Research, 1987-1990.

PepsiCo Research Chair, Northwestern University, 1990.

Kellogg Research Professorship, Northwestern University, 1989.

National Science Foundation Research Grant, 1987-1988.

Buchanan Chair, Kellogg Graduate School of Management, Northwestern University, 1987-1988.

IBM Chair, Kellogg Graduate School of Management, Northwestern University, 1986-1987.

Teaching

Courses taught: Pricing Strategy; Information, Communication, and Competition (economics of strategy and competition); Intermediate Microeconomic Theory; Managerial Economics (microeconomic theory as applied to business strategy and decision making) at the M.B.A. level, The Economics of Information at the Ph.D. level.

Also qualified to teach: graduate Microeconomic Theory; Industrial Organization and Labor Economics; the Economics of Personnel; Public Finance; Project Evaluation; Applied Game Theory.

Professional history

2019–Present	*Vice President*, Charles River Associates, Chicago, IL
2018–2019	*Principal and Senior Managing Director*, Ankura Consulting Group, Chicago, IL
2010-2018	*Principal and Managing Director*, Navigant Economics, Chicago, IL
2000-2016	*Adjunct Associate Professor*, Northwestern University, Evanston, IL
1995-2010	*Managing Director*, LECG, LLC, Evanston, IL
1993-1995	*Visiting Assistant Professor of Managerial Economics*, Northwestern University, Evanston, IL
1985-1992	*Assistant Professor of Managerial Economics*, Northwestern University, Evanston, IL
1992-1993	*National Fellow*, Hoover Institution at Stanford University, Stanford, CA
1983-1984	*Instructor*, University of Chicago Department of Economics, Chicago, IL
1979-1980	*Staff Economist*, Civil Aeronautics Board, Office of Economic Analysis, Washington, D.C.

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APPENDICES

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A. Profiles of the Major RAN Equipment Providers

i. Huawei

1. Huawei Technologies Co., Ltd. ("Huawei") is a wholly-owned subsidiary of Huawei Investment & Holding Co., Ltd. ("Huawei Group"), headquartered in Shenzhen in the People's Republic of China.[1] Huawei Group operates in many different facets of the communications industry, from designing and manufacturing wired and wireless communication infrastructure equipment to developing, testing, and producing smartphones.[2] I understand that Huawei is responsible for "development, manufacture and sale of telecommunication and related products and provision of support and maintenance services."[3]

2. Huawei Group has historically operated in China since its founding in 1987; however, it has expanded into international markets in recent years.[4]

3. Huawei Group conducts business in three operating segments: 1) Carrier Business, 2) Enterprise Business, and 3) Consumer Business.[5] Huawei Group's Carrier Business segment designs, manufactures and sells fixed and wireless network equipment, and related software, among other products.[6] This segment provides services to global telecommunications carriers, including services such as simplified operations and maintenance of 5G networks, cloud-network convergence services, and network rollout services.[7]

4. Huawei Group's Enterprise Business segment develops information and communications technology (abbreviated as "ICT") products and solutions by using, for example, cloud

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[1] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, pp. 74, 123.

[2] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, pp. 97, 123.

[3] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 123.

[4] Edwin Chan, "Huawei's Profit Jumps as It Makes Headway Beyond China," *Bloomberg Technology*, Updated April 1, 2016, at http://www.bloomberg.com/news/articles/2016-04-01/huawei-s-profit-jumps-as-it-makes-headway-beyond-slowing-china.

[5] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 97.

[6] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, pp. 97, 123.

[7] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, pp. 21 and 97.

computing, big data and Internet of Things ("IoT"), and software-defined networking.[8] Huawei Group provides these solutions to customers in various industries including governments, public utilities, energy, transport manufacturing, and finance.[9] Huawei Group's Consumer Business segment develops, manufactures, and sells smartphones, tablets, wearable devices, converged home devices, and applications for these devices for consumers and businesses.[10]

5. Huawei Group generated approximately $107 billion in revenue in 2018. The Carrier segment accounted for approximately 41 percent of total revenues, the Enterprise segment accounted for approximately 10 percent of revenues, the Consumer segment accounted for approximately 48 percent of revenues, and the rest was specified as unallocated revenue.[11]

ii. Ericsson

6. Ericsson is a publicly-owned company headquartered in Stockholm, Sweden.[12] Ericsson divides its market activities into four segments: Networks, Digital Services, Managed Services, and Emerging Business and Other.[13] The Networks segment provides hardware, software, and services to carriers to build and evolve their mobile networks; Digital Services provides software to customers to operate and monetize their mobile networks; Managed Services provides services related to network operations; and Emerging Business and Other offers new innovative services such as Internet of Things.[14] Ericsson has three wholly-owned subsidiaries in China. Ericsson also has a joint venture with Nanjing Panda Electronics, Nanjing Ericsson Panda Communication Co., Ltd. Nanjing Panda Electronics is partially owned by the Chinese government.[15] In addition, some of Ericsson's

[8] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, pp. 97, 153.
[9] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 97.
[10] Huawei Investment & Holding Co., Ltd., 2018 Annual Report, pp. 97, 123.
[11] "Huawei Investment Holding Co., Ltd., Financials" S&P Capital IQ.
[12] Telefonaktiebolaget LM Ericsson, 2018 Annual Report, pp. 133, 205.
[13] Telefonaktiebolaget LM Ericsson, 2018 Annual Report, p. 9.
[14] Telefonaktiebolaget LM Ericsson, 2018 Annual Report, p. 9.
[15] Telefonaktiebolaget LM Ericsson, 2018 Annual Report, pp. 107-108; "Investor Relations: Ownership," Panda Electronics Group, Co., Ltd., at http://www.panda.cn/gqjg/index_393.aspx.

production sites are in China.[16] Ericsson's total revenue in 2018 was approximately $23 billion.[17]

iii. Nokia

7. Nokia is a public company incorporated and domiciled in Helsinki, Finland.[18] Nokia's business is organized into seven groups: Mobile Networks, Fixed Networks, Global Services, IP/Optical Networks, Nokia Software, Nokia Enterprise (these six groups together constitute "Networks business"), and Nokia Technologies.[19] Mobile Networks provides technology for mobile access and microwave transport ranging from 2G to 5G;[20] Fixed Networks serves carriers and provides copper, cable, fiber, fixed wireless access, and Wi-Fi technologies;[21] Global Services provides services for mobile networks and managed services for the fixed, mobile, applications, IP, and optical domains;[22] IP/Optical Networks provides routing and optical technologies to carriers;[23] Nokia Software provides software to carriers and large enterprises to monetize, automate, make more intelligent, and/or upgrade networks;[24] Nokia Enterprise provides services related to the implementation and management of enterprise networks;[25] and Nokia Technologies focuses on the licensing of Nokia intellectual property, including patents, technologies, and the Nokia brand, and managing patent portfolio.[26] Nokia has a China-based joint venture called Nokia Shanghai Bell. Nokia holds 50 percent of shares plus one share ownership in Nokia Shanghai Bell's parent company, Nokia Shanghai Bell Co., Ltd. All other shares of Nokia Shanghai Bell Co., Ltd. are owned by the state-controlled China Huaxin.[27] Nokia also has one of its

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[16] Telefonaktiebolaget LM Ericsson, 2018 Annual Report, p. 40.
[17] Telefonaktiebolaget LM Ericsson, Available: S&P Capital IQ, McGraw Hill Financial.
[18] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 136.
[19] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 3.
[20] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 12.
[21] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 14.
[22] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 16.
[23] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 18.
[24] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 20.
[25] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 22.
[26] Nokia Corporation, Form 20-F, for the fiscal year ended December 31, 2018, p. 24.
[27] Nokia Corporation, 2018 Annual Report, pp. 170-171.

manufacturing sites located in China.[28] Nokia's revenue was approximately $25 billion in 2018.[29]

iv. Samsung

8. Samsung is headquartered in Suwon, the Republic of Korea.[30] Samsung and its subsidiaries operate the following four segments: Consumer Electronics, Information Technology & Mobile communications, Device Solutions, and Harman. The Consumer Electronics segments includes digital TVs, monitors, air conditioners, and refrigerators; the Information Technology & Mobile communications includes mobile phones, communications systems, and computers; Device Solutions includes products such as memory, foundry and system LSI in the semiconductor business and LCD and OLED panels in the display business; and Harman includes connected car systems, visual products, audio products, enterprise automation solutions, and connected services.[31] Samsung has numerous subsidiaries in China, including R&D centers and manufacturing facilities.[32] Samsung is the biggest seller of wireless handsets worldwide.[33] Samsung's revenue was approximately $214 billion in 2018.[34]

v. ZTE

9. ZTE is based in Shenzhen, China.[35] ZTE's business is divided into three segments: carriers' network, government and corporate business, and consumer business. ZTE offers wireless products including base stations, network optimization tools, controllers, network

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[28] Nokia Corporation, 2018 Annual Report, p. 108.

[29] Nokia Corporation, Available: S&P Capital IQ, McGraw Hill Financial.

[30] "Company Overview of Samsung Electronics Holding Co., Ltd.," Bloomberg L.P., at https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=91868.

[31] "Consolidated Financial Statements of Samsung Electronics Co., LTD. and Its Subsidiaries. Index to Financial Statements," p. 14.

[32] "Consolidated Financial Statements of Samsung Electronics Co., LTD. and Its Subsidiaries. Index to Financial Statements," Notes to the Consolidated Financial Statements, pp. 18-24.

[33] "Smartphone Shipments Experience Deeper Decline in Q1 2019 with a Clear Shakeup Among the Market Leaders, According to IDC," *IDC Corporate USA*, April 30, 2019, at https://www.idc.com/getdoc.jsp?containerId=prUS45042319.

[34] "Samsung Electronics Co., Ltd. KOSE A005930 Financials," S&P Capital IQ.

[35] "About Us," ZTE USA, at https://www.zteusa.com/about-us-old.

management products, and wireless infrastructure products. It also provides cloud computing and cloud infrastructure products, home media center products, and handsets.[36]

10. ZTE's revenue in 2018 was approximately $12.7 billion, approximately 64 percent of which came from its domestic market.[37] Carriers' networks revenue accounted for approximately 67 percent of ZTE's 2018 revenue, consumer business revenue accounted for approximately 22 percent, and government and corporate business accounted for approximately 11 percent.[38]

B. ESTIMATE OF THE IMPACT OF THE PENETRATION RATE OF NEW WIRELESS TECHNOLOGY GENERATION ON GDP PER CAPITA

11. To quantify the impact of the penetration rate of new wireless technology generation on GDP per capita I estimate the following regression model:

$$\begin{aligned}\ln(GDP\ per\ Capita_{it}) &= \alpha_0 + \alpha_1 * \ln(GDP\ per\ Capita_{it-1}) + \alpha_2 \\ &* \ln(GDP\ per\ Capita_{it-2}) + \alpha_3 * \ 4G\ Penetration\ Rate_{it} \\ &+ \alpha_4 * Mobile\ Penetration\ \mathrm{Rate}_{it} + \alpha_5 \\ &* Trade\ (\%\ of\ GDP)_{it} + \alpha_6 * Investment\ (\%\ of\ GDP)_{it} \\ &+ \alpha_7 * \ln(Labor_{it}) + \epsilon_{it}\end{aligned} \tag{1}$$

where $GDP\ per\ Capita_{it}$ is GDP per capita in 2010 USD at time t in country i; 4G $Penetration\ Rate_{it}$ is the penetration rate of 4G in country i at time t;[39] $Mobile\ Penetration\ Rate_{it}$ is the overall penetration rate of mobile phones (of any technology) in country i at time t; $Trade\ (\%\ of\ GDP)_{it}$ is the sum of exports and imports of goods and services as a share of GDP in country i at time t; $Investment\ (\%\ of\ GDP)_{it}$ is the net investment in nonfinancial assets measured as a share of GDP in country i at time t; $Labor_{it}$ is the total supply of labor in country i at time t; $\alpha_0, \ldots, \alpha_7$ are the regression

[36] See "Company Overview of ZTE Corporation," Bloomberg L. P., at https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=3051118; Annual Report, ZTE Corporation, 2018 (hereafter, *2018 ZTE Annual Report*), p. 31.

[37] *2018 ZTE Annual Report*, p. 31.

[38] ZTE Corporation, Available: S&P Capital IQ, McGraw Hill Financial.

[39] The 4G penetration rate in a country is calculated as the number of 4G-capable mobile devices in a country divided by the total population of that country.

coefficients to be estimated; and ϵ_{it} is the regression error term that captures idiosyncratic factors in country i at time t that are not captured by the explanatory variables in the regression.

12. The coefficient of interest is α_3. A positive and significant estimate of α_3 is consistent with the conclusion that a higher 4G penetration rate results in a higher GDP per capita. The estimated coefficient is the estimated percentage effect on GDP per capita of an increase in the 4G penetration rate of one percentage point.

13. I examine data from GSMA Intelligence on 4G penetration rates and mobile penetration rates in Australia, Canada, China, Germany, Japan, South Korea, the United States, and the United Kingdom. Data on GDP per capita, investment, labor force, and trade are taken from the World Bank's World Development Indicators ("WDI") database.[40] I exclude China from the regression sample because many observations are missing for this country in the WDI database.

14. The regression equation (1) might suffer from endogeneity. Endogeneity arises when there is a reverse causality issue or omitted variable bias. A reverse causality issue arises when there is a causal relationship between the outcome variable (e.g., GDP per capita) and an independent variable (e.g., the 4G penetration rate) in both directions. An omitted variable bias exists when there is a variable that is not included in the regression model but that affects both the outcome variable and one or several independent variables. For example, if certain government regulations have an effect on both GDP per capita and the 4G penetration rate, then the estimated effect of the 4G penetration rate on GDP per capita may be biased.

[40] See "Databank. World Development Indicators," the World Bank, at https://databank.worldbank.org/data/source/world-development-indicators.

15. My regression equation follows the regression specification estimated by Deloitte in its 2012 report.[41] Similar to the estimation strategy in Deloitte's report, I use the Arellano-Bond estimator to account for both types of endogeneity.[42] I apply the one-step Arellano-Bond estimator with 4G penetration rate and mobile penetration rate as contemporaneously endogenous variables and labor, investment, and trade as predetermined variables.[43] Exhibit B.1 shows the results.

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[41] "What is the impact of mobile telephony on economic growth? A Report for the GSM Association." Deloitte, November 2012, pp. 13-14. Unlike the Deloitte study, I do not include government expenditures in my model because including this variable results in the violation of the critical assumption for Arellano-Bond estimator that the regression error terms are serially uncorrelated. See A. Colin Cameron and Pravin K. Trivedi, MICROECONOMETRICS USING STATA, Revised ed. (College Station, TX: StataCorp LP, 2010), p. 300.

[42] A. Colin Cameron and Pravin K. Trivedi, MICROECONOMETRICS USING STATA, Revised ed. (College Station, TX: StataCorp LP, 2010), pp. 293-301.

[43] Predetermined regressors are regressors that are correlated with past errors and are uncorrelated with present or future errors. Contemporaneously endogenous regressors are regressors that are correlated with past and present errors and are uncorrelated with future errors. See A. Colin Cameron and Pravin K. Trivedi, MICROECONOMETRICS USING STATA, Revised ed. (College Station, TX: StataCorp LP, 2010), p. 295.

Exhibit B.1

Regression Results for the Estimate of the Impact of the 4G Penetration Rate on GDP per Capita. Arellano-Bond Estimator, 2012-2017

	(1) $\ln(\text{GDP per Capita}_t)$	(2) $\ln(\text{GDP per Capita}_t)$
$\ln(\text{GDP per Capita})_{t-1}$	0.207 (0.132)	0.503** (0.213)
$\ln(\text{GDP per Capita})_{t-2}$	0.073 (0.059)	0.022 (0.081)
$\text{Investment (\% of GDP)}_t$	−0.013** (0.006)	
$\text{Trade (\% of GDP)}_t$	−0.001*** (0.000)	−0.001*** (0.000)
$\ln(\text{Labor})_t$	0.182** (0.083)	0.031 (0.144)
$\text{4G Penetration Rate}_t$	0.043*** (0.014)	0.035** (0.017)
$\text{Mobile Penetration Rate}_t$	0.030* (0.018)	0.021 (0.015)
Observations	36	42

Notes:

[1] Models (1) and (2) are estimated using one-step Arellano-Bond estimator. 4G penetration rate and mobile penetration rate are assumed to be contemporaneously endogenous; trade, investment, and labor are assumed to be pre-determined.

[2] Robust standard errors are in parentheses.

[3] *significant at 90% level; **significant at 95% level; and ***significant at 99% level.

Sources:

[1] "DataBank. World Development Indicators," The World Bank, Series "GDP per capita (constant 2010 US$)," "Trade (% of GDP)," "Net investment in nonfinancial assets (% of GDP)," "Labor force, total," at https://databank.worldbank.org/data/source/world-development-indicators.

[2] GSMA Intelligence 2019 mobile subscriptions and statistics reports for Australia, Canada, Germany, Japan, South Korea, the U.K., and the U.S.

16. I run two regression models: Model (1) uses all variables from equation (1); Model (2) uses all variables from equation (1) but excludes net investment as a share of GDP, because this variable is missing for all counties in 2017, except for Canada. The results of the two models are similar. Model (1) indicates that when the 4G penetration rate increases by 1 percentage point, GDP per capita increases by 0.043 percent. Model (2) indicates that when the 4G penetration rate increases by 1 percentage point, GDP per capita increases by 0.035 percent. In my estimate of the impact of 5G adoption delay, I use the more conservative result of Model (2).

17. To ensure the validity of my estimates, I perform two specification tests of my estimator. I run the Arellano-Bond test for zero autocorrelation (i.e., no serial correlation in an error

term is a key assumption of the Arellano-Bond estimator). I also run the Sargan test for overidentifying restrictions.[44] Both tests do not reject the null hypothesis at a 95 percent confidence level that the model assumptions are met.

18. Exhibit B.2 shows my calculations of the cost of delay in 5G penetration rate on U.S. GDP for delay durations of 6, 12, 18, and 24 months. To calculate the incremental cost of the delay associated with the absence of Huawei, I subtract the cost of delay resulting from the spectrum gap—6 month delay—from the estimated cost associated with delay durations equal to 12, 18, and 24 months. Exhibit VIII.1 shows that the estimated cost of delay resulting from the Huawei ban ranges from approximately $104 billion to $241 billion.

[44] A. Colin Cameron and Pravin K. Trivedi, MICROECONOMETRICS USING STATA, Revised ed. (College Station, TX: StataCorp LP, 2010), pp. 300-301.

Exhibit B.2
Losses to the U.S. Economy Due to Delay in 5G Deployment Under Different Delay Scenarios

Year	5G Penetration Rate without Delay	5G Penetration Rate with Delay	GDP per Capita	Decline in GDP per Capita Because of Delay in 5G Deployment	U.S. Population Estimate	Decline in Total Annual Real GDP Because of Delay
6 Months Delay	**[A]**	**[B]**	**[C]**	**[D]=0.035*([A]-[B])*[C]**	**[E]**	**[F]=[D]*[E]**
2018	0.00%	0.00%	$ 62,590	$ -	327,435,500	$ -
2019	0.13%	0.04%	$ 63,593	$ 2	329,685,382	$ 642,181,059
2020	0.50%	0.22%	$ 64,611	$ 6	331,950,723	$ 2,083,436,756
2021	2.82%	1.29%	$ 65,640	$ 35	334,231,630	$ 11,769,467,827
2022	8.04%	5.02%	$ 66,657	$ 71	336,528,209	$ 23,753,623,884
2023	19.85%	13.43%	$ 67,654	$ 152	338,840,569	$ 51,458,005,182
2024	33.92%	26.25%	$ 68,584	$ 184	341,168,817	$ 62,865,037,527
Discounted Present Value of Total Decline in GDP (in 2019 Dollars)						**$ 132,839,848,781.92**
12 Months Delay	**[A]**	**[B]**	**[C]**	**[D]=0.035*([A]-[B])*[C]**	**[E]**	**[F]=[D]*[E]**
2018	0.00%	0.00%	$ 62,590	$ -	327,435,500	$ -
2019	0.13%	0.00%	$ 63,593	$ 3	329,685,382	$ 935,749,543
2020	0.50%	0.13%	$ 64,610	$ 8	331,950,723	$ 2,796,646,215
2021	2.82%	0.50%	$ 65,637	$ 53	334,231,630	$ 17,797,358,967
2022	8.04%	2.82%	$ 66,635	$ 122	336,528,209	$ 40,996,142,843
2023	19.85%	8.04%	$ 67,580	$ 279	338,840,569	$ 94,627,430,821
2024	33.92%	19.85%	$ 68,380	$ 337	341,168,817	$ 114,963,344,560
Discounted Present Value of Total Decline in GDP (in 2019 Dollars)						**$ 236,486,410,620.11**
18 Months Delay	**[A]**	**[B]**	**[C]**	**[D]=0.035*([A]-[B])*[C]**	**[E]**	**[F]=[D]*[E]**
2018	0.00%	0.00%	$ 62,590	$ -	327,435,500	$ -
2019	0.13%	0.00%	$ 63,593	$ 3	329,685,382	$ 935,749,543
2020	0.50%	0.04%	$ 64,610	$ 10	331,950,723	$ 3,453,576,533
2021	2.82%	0.22%	$ 65,635	$ 60	334,231,630	$ 19,927,823,827
2022	8.04%	1.29%	$ 66,627	$ 158	336,528,209	$ 53,019,346,951
2023	19.85%	5.02%	$ 67,535	$ 351	338,840,569	$ 118,796,380,549
2024	33.92%	13.43%	$ 68,262	$ 490	341,168,817	$ 167,041,651,784
Discounted Present Value of Total Decline in GDP (in 2019 Dollars)						**$ 314,864,559,541.69**
24 Months Delay	**[A]**	**[B]**	**[C]**	**[D]=0.035*([A]-[B])*[C]**	**[E]**	**[F]=[D]*[E]**
2018	0.00%	0.00%	$ 62,590	$ -	327,435,500	$ -
2019	0.13%	0.00%	$ 63,593	$ 3	329,685,382	$ 935,749,543
2020	0.50%	0.00%	$ 64,610	$ 11	331,950,723	$ 3,753,887,536
2021	2.82%	0.13%	$ 65,634	$ 62	334,231,630	$ 20,657,069,508
2022	8.04%	0.50%	$ 66,624	$ 176	336,528,209	$ 59,177,938,008
2023	19.85%	2.82%	$ 67,513	$ 402	338,840,569	$ 136,355,533,804
2024	33.92%	8.04%	$ 68,187	$ 618	341,168,817	$ 210,771,995,724
Discounted Present Value of Total Decline in GDP (in 2019 Dollars)						**$ 373,511,733,831.82**

Notes:
[1] I assume that without a delay in 5G deployment, 5G penetration rate between Q2 2019 and Q4 2024 would replicate 4G penetration rate between Q1 2009 and Q3 2014. I assume that if 5G deployment were delayed, 5G penetration rate would follow the same trajectory as in the scenario without delay, but its start would be delayed by the time equal to the duration of delay. For example, when 5G deployment is delayed by six months, 5G penetration rate is assumed to be zero in Q2 2019 and Q3 2019 and for t = Q4 2019-Q4 2024 it is assumed that the 5G penetration rate in Q_t equals the 5G penetration rate from the scenario without delay in Q_{t-2}. The annual penetration rate is calculated as the average of quarterly penetration rates.
[2] I assume that if 5G deployment is delayed, it will take 21 quarters, or 5.25 years, after the start of 5G deployment for the U.S. to reach the same penetration rate it would have if there were no delay in 5G deployment.
[3] The FCC intends to release mid-band spectrum to carriers in 2019-2020, but no date has been set. I assume that the mid-band spectrum will be released to carriers in Q3 2019, therefore, I assume that the delay associated with the spectrum gap is 6 months, or two quarters.
[4] I assume that a 1 percentage point decline in 5G penetration rate would result in a 0.035 percent decline in GDP per capita. This assumption is based on the regression estimates reported in Exhibit B.1.
[5] Real GDP per capita in [C] is assumed to grow at the rate of 1.6 percent per year. This growth rate is calculated as the compounded growth rate of annual real GDP per capita between 2012 and 2018, i.e., real GDP per capita growth rate = (real GDP per capita_{2018}/real GDP per $\text{capita}_{2012})^{(1/6)}$-1.
[6] U.S. population in [E] is assumed to grow at the rate of 0.69 percent per year. This growth rate is calculated as the compounded growth rate of U.S. population between 2012 and 2018, i.e., the population growth rate = (U.S. population_{2018}/U.S. $\text{population}_{2012})^{(1/6)}$-1
[7] The discounted present value of total decline in real GDP is calculated according to the following formula $\Sigma_{t = 2019,...2024}$ Real $\text{GDP}_t/(1+0.035)^{(t-2019)}$, where 3.5 percent is the annual social discount rate from Mark A. Moore and Aidan R. Vining, "The Social Rate of Time Preference and the Social Discount Rate." *Mercatus Research Paper, December* (2018), p. 3, at https://www.mercatus.org/system/files/moore_and_vining_-_mercatus_research_-_a_social_rate_of_time_preference_approach_to_social_discount_rate_-_v1.pdf.

Sources:
[1] "Real gross domestic product per capita, Chained 2012 Dollars, Annual, Seasonally Adjusted Annual Rate," Federal Reserve Bank of St. Louis, accessed June 6, 2019, at https://fred.stlouisfed.org/series/A939RX0Q048SBEA.
[2] "Gross domestic product per capita, Dollars, Annual, Not Seasonally Adjusted," Federal Reserve Bank of St. Louis, accessed June 6, 2019, at https://fred.stlouisfed.org/series/A939RX0Q048SBEA#0.
[3] "Population, Thousands, Annual, Not Seasonally Adjusted," Federal Reserve Bank of St. Louis, accessed June 6, 2019, at https://fred.stlouisfed.org/series/POPTHM#0.
[4] Exhibits B.1 and B.3.
[5] GSMA Intelligence, "Country Dashboard," 2019, for the United States.
[6] "DataBank. World Development Indicators," The World Bank, Series "GDP per capita (constant 2010 US$)," "Trade (% of GDP)," "Net investment in nonfinancial assets (% of GDP)," "Labor force, total," at https://databank.worldbank.org/data/source/world-development-indicators.
[7] Mark A. Moore and Aidan R. Vining, "The Social Rate of Time Preference and the Social Discount Rate." *Mercatus Research Paper, December* (2018), at https://www.mercatus.org/system/files/moore_and_vining_-_mercatus_research_-_a_social_rate_of_time_preference_approach_to_social_discount_rate_-_v1.pdf, p. 3.
[8] Statement of Chairman Ajit Pai, Federal Communications Commission, Hearing on "Oversight of the Federal Communications Commission," Before the United States Senate Committee on Commerce, Science, and Transportation, June 12, 2019, available at https://docs.fcc.gov/public/attachments/DOC-357959A1.pdf.

i. Estimate of the Relationship Between Delay in 5G Deployment and Delay in 5G Adoption

19. Using GSMA 4G penetration rate data for Australia, Canada, China, Germany, Japan, South Korea, the United States, and the United Kingdom, I estimate the relationship between the duration of 4G deployment delay and the time it took a country to catch up with the penetration rate it would have had if its 4G deployment had not been delayed. I assume that this relationship will be the same for 5G.

20. To estimate that relationship, for each pair of countries for which 4G penetration started in different quarters, I identify the leader country and the follower country. I calculate the amount of delay as the number of quarters between the time when the leader country started deploying 4G and when the follower country started deploying 4G. I assume that without the delay, the follower country would have had the same trajectory of 4G penetration rate as the leader country. I calculate the number of quarters it took the follower country to catch up with the leader country in 4G penetration rate.[45] In 13 of the 27 country pairs, the

[45] I consider that a follower country catches up with a leader country if its 4G penetration rate stays consistently equal to or above the 4G penetration rate of the leader country.

4G penetration rate of the follower country never caught up with the 4G penetration of the leader country. If the follower country never caught up, I assign the catch-up time to be equal to 40 quarters, because 40 quarters is the average number of quarters between the quarter when a country started 4G deployment and the quarter when the same country started 5G deployment.[46]

21. I identified 27 country pairs in my data.[47] To estimate the relationship between the delay time and the catch-up time, I estimated the following regression:

$$Catch\ up\ Time_i = \beta_0 + \beta_1 * Delay\ Time_i + v_i, \tag{2}$$

where $Catch\ up\ Time_i$ is the time in quarters it took the follower country in country pair i to achieve the same 4G penetration rate as the leader country in that country-pair; $Delay\ Time_i$ is the number of quarters the follower country was behind the leader country in 4G deployment in country pair i; and v_i is the regression error term that captures idiosyncratic factors in country pair i that are not captured by the explanatory variables in the regression.

[46] There are only three countries in my sample that had deployed 5G mobile networks at the time of this report: South Korea, the United States, and the United Kingdom. The average number of quarters between the deployment of 4G and 5G equals 40.

[47] Australia and Canada reached non-zero 4G penetration rates in the same quarter. I did not include this country pair in my analysis.

Exhibit B.3
Estimated Impact of Delay in 5G Deployment on 5G Adoption

	Catch up Time
Delay Time	0.816**
	(0.333)
Constant	17.847***
	(5.483)
Observations	27
R^2	0.131

Note: ***significant at 99% level; ** significant at 95% level.

Source: GSMA Intelligence 2019 mobile subscriptions and statistics reports for Australia, Canada, China, Germany, Japan, South Korea, the U.K., and the U.S.

22. Using the regression results, I calculate the expected time it will take the United States to achieve the 5G penetration rate it would have achieved without delay. The predicted time to catch up equals 17.847 + 0.816 x delay time (in quarters), where the delay time takes values 2 quarters (delay associated with spectrum gap), and 4, 6, and 8 quarters (delay associated with spectrum gap plus the additional delay associated with the absence of Huawei from the U.S. market). I estimate that the predicted time of catch up for the assumed durations of delay of 2, 4, 6, and 8 quarters equals 4.87 years, 5.28 years, 5.69 year, and 6.09 years, respectively.

23. Based on these results, I assume for purposes of my estimate of the costs to the U.S. economy of delayed deployment of 5G networks due to excluding Huawei that the time to overcome the delay equals 5.25 years. This assumed delay is shorter than the estimated delay in each scenario in which an additional delay is caused by the absence of Huawei. This assumption is therefore conservative, because it shortens the period of 5G penetration rate delay in the scenarios where part of the delay is caused by Huawei's absence and increases the period of delay for the scenario where the entire delay is caused by the spectrum gap.

C. Calculation of the Effect on Equipment Vendor Prices of Excluding Huawei from Sales of RAN Network Equipment in the United States

24. Estimation of the extent to which prices for RAN equipment are higher in the United States due to the absence of Huawei requires several parameters: (1) revenue shares of the equipment vendors in the United States and an estimate of their shares in the but-for world in which Huawei is present and in the actual world in which Huawei is restricted; (2) diversion ratios between Huawei and its competitors; (3) gross margins of each company in the market for RAN equipment (including Huawei); and (4) ratios of Huawei's price to the prices of other firms in the market for RAN equipment when Huawei is present in the U.S. market. Below I discuss each of these parameters and how I calculated their values.

25. Because I do not have data on vendors' RAN equipment revenues shares in the United States, I assume that the vendors' RAN equipment revenue shares in the United States when Huawei is restricted from the market would be equal to the vendors' 2018 revenue shares in the market for all RAN equipment in North America. As I explained in Section VI of my report, vendors' revenue shares in North America primarily reflect vendors' revenue shares in the United States.

26. Huawei's revenue share in the United States if Huawei is allowed to participate in the U.S. market without any limitations is not observed, because Huawei has never been allowed to enter the U.S. market to the same extent as it has, for example, in Europe.[48] I consider three scenarios for what Huawei's revenue share would be if it were allowed to participate in the U.S. market: (1) Huawei's revenue share would equal its revenue share in Europe, (2) Huawei's revenue share would equal its average revenue share in all regions except North America, and (3) Huawei's revenue share would equal its average revenue share worldwide including the United States.[49]

27. I use revenue share data for 2018 because this is the most recent year for which data are available. To calculate the revenue shares of other vendors in the but-for world in which Huawei is present in the U.S. market, I apply the following formula:

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[48] See Section VI of my report for background related to Huawei's current presence in the United States and the rest of the world.

[49] The revenue shares are calculated using the data provided by Dell'Oro Group.

$$rs_i = RS_i - D_{Hi}(rs_H - RS_H), \tag{3}$$

where rs_i is vendor i's revenue share in the United States in the but-for world in which Huawei is allowed to participate fully in the U.S. market; rs_H is the assumed revenue share of Huawei in the United States in the but-for world; RS_i is vendor i's revenue share in the United States in the actual world; RS_H is Huawei's revenue share in the actual world (as I explained in Section VI, Huawei has a very small revenue share in the United States serving primarily rural carriers); and D_{Hi} is the diversion ratio from Huawei to vendor i.

28. Diversion ratios quantify the extent to which products substitute for each other. The diversion ratio between two products is "the fraction of unit sales lost by the first product due to an increase in its price that would be diverted to the second product."[50] The higher is the diversion ratio between two vendors, the greater is the pricing discipline that the vendors' products impose on each other; and, conversely, the greater is the likelihood that one product's price will rise if the other is absent.[51]

29. I assume that the diversion ratio from product 1 to product 2 when firm 1 is absent from the market equals the revenue share of firm 2 divided by the sum of revenue shares of all firms in the market except firm 1.[52]

30. Gross margin is the difference between a firm's net sales revenue and its cost of goods sold, divided by net sales revenue.[53] I use each RAN vendors' gross margins provided by S&P Capital IQ Financial Communications as my estimate of its gross margin on RAN equipment.[54]

31. Finally, to calculate the ratio of Huawei's price to the price of another vendor (i.e., Ericsson, Nokia, Samsung, ZTE, and other) I use the global average sales prices of LTE-FDD products as provided by Dell'Oro Group. LTE-FDD is the most commonly deployed

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[50] *2010 Horizontal Merger Guidelines*, Sec. 6.1.
[51] *2010 Horizontal Merger Guidelines*, Sec. 6.1.
[52] Carl Shapiro, "Mergers with Differentiated Products," *Antitrust*, Spring 1996, p. 25, at http://faculty.haas.berkeley.edu/shapiro/diversion.pdf.
[53] "Gross Margin Definition," Investopedia, at https://www.investopedia.com/terms/g/grossmargin.asp.
[54] S&P Capital IQ Financial Communications provides marketing and communications solutions and investor education for financial services firms. See "Company Overview of S&P Capital IQ Financial Communications," Bloomberg, at https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=22677616.

4G mobile wireless technology in the world.[55] Similar to 5G, it is not restricted to a single country or region (unlike some technologies in 2G and 3G), and therefore it is reasonable to assume that all of the equipment vendors produce material quantities of LTE-FDD equipment.[56]

32. If firms compete on prices and if demand is linear, the price increase of vendor *i* due to the restrictions on Huawei's participation in the market is analogous to a post-merger price increase of vendor i, and can be calculated according to the following formula:[57]

$$\frac{p_i^* - \overline{p_\iota}}{\overline{p_\iota}} = \frac{2D_{iH}M_H\frac{\overline{p_H}}{\overline{p_\iota}} + D_{Hi}(D_{iH} + D_{Hi})M_i}{4 - (D_{iH} + D_{Hi})^2} \tag{4}$$

where $\overline{p_H}$ and $\overline{p_\iota}$ are the prices of products sold by Huawei and vendor *i*, respectively (*i* indexes Ericsson, Nokia, Samsung, ZTE, and a hypothetical firm with the same market share as the remaining other firms) in the but-for world, and p_i^* is the price of firm *i* in the actual world; D_{Hi} measures the diversion ratio from Huawei's product to firm i's product (that is, it is the share of sales lost by Huawei if it were to raise the price on its product that would be captured by firm i), and D_{iH} measures the diversion ratio from firm i's product to Huawei's product (which is defined analogously to D_{Hi}).[58] Finally, M_H and M_i are gross profit margins of Huawei and firm *i*, respectively.

33. Exhibit C.1 shows the result of my analysis under the three assumptions of Huawei's revenue share in the United States if Huawei is allowed to sell RAN equipment in the

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[55] See Section VII.C.

[56] I did not use prices of 5G RAN, because not all vendors had sales of 5G RAN equipment in Q4 2018 – Q1 2019, and Huawei's price dropped dramatically compared to prices of other vendors in Q1 2019. This may have occurred as a result of limitations placed on Huawei in several countries worldwide. See "M26A_5G_NR_Sub_6_GHz_Vendor Table_1Q19.xlsx" and "M27A_5G_NR_Millimeter_Wave_Vendor Table_1Q19.xlsx;" Katharina Buchholz, "Which Countries Have Banned Huawei?," Statista, May 21, 2019, at https://www.statista.com/chart/17528/countries-which-have-banned-huawei-products/.

[57] While this is a standard economic analysis, it incorporates several additional assumptions, including (1) that firms engage in Bertrand competition (i.e., firms are competing on prices), (2) that products offered by vendors in this market are close substitutes, and (3) that the marginal costs of firms in the market are constant. Carl Shapiro "Unilateral Effects Calculations," last updated: October 2010, at http://faculty.haas.berkeley.edu/shapiro/unilateral.pdf, pp. 2-5; Carl Shapiro, "Mergers with Differentiated Products," *Antitrust*, Spring 1996, pp. 24-27, at http://faculty.haas.berkeley.edu/shapiro/diversion.pdf.

[58] Carl Shapiro, "Unilateral Effects Calculations," last updated October 2010, at http://faculty.haas.berkeley.edu/shapiro/unilateral.pdf, p. 3.

United States. The exhibit indicates that in the absence of Huawei from the U.S. market for RAN equipment the prices of smaller vendors (Samsung, ZTE, and other vendors[59]) are higher by approximately 4.8-7.3 percent, Nokia's prices are higher by 12.5-15.8 percent, and Ericsson's prices are higher by 14.6-18.4 percent.

34. I also calculate the weighted average price effect, where each vendor's price increase is weighted according to its revenue share when Huawei is absent from the market. I estimate that, on average, Huawei's absence from the U.S. market for RAN equipment causes prices to be higher by 12.6-16.0 percent.

[59] These are vendors other than Huawei, Ericsson, Nokia, Samsung, and ZTE.

Exhibit C.1
Estimated Price Increase as a Result of Restrictions on Huawei's Participation in the U.S. Market for RAN Equipment

Vendor	Estimated Price Increase Resulting from Huawei's Absence From the U.S. Market (%)		
	Scenario 1: Huawei's Revenue Share in the U.S. in the Absence of Restrictions Equals Huawei's Revenue Share in Europe	Scenario 2: Huawei's Revenue Share in the U.S. in the Absence of Restrictions Equals Huawei's Revenue Share in All Regions Except North America	Scenario 3: Huawei's Revenue Share in the U.S. in the Absence of Restrictions Equals Huawei's Revenue Share Worldwide
ERICSSON	16.4%	18.4%	14.6%
NOKIA	14.0%	15.8%	12.5%
SAMSUNG	6.3%	7.3%	5.5%
ZTE	5.6%	6.4%	4.8%
OTHER	5.7%	6.5%	4.9%
Weighted Average	**14.2%**	**16.0%**	**12.6%**

Notes:

[1] I assume that gross margins for Huawei's and Samsung's network equipment, which are not reported separately from their handset and other business lines, are equal to Ericsson's gross margin for network equipment, which is a conservative assumption.

[2] Each vendor's price increase from the absence of Huawei from the U.S. market equals $[2*D_{iH}*M_H*(p_H/p_i)+D_{Hi}*(D_{Hi}+D_{iH})*M_i]/[4-(D_{Hi}+D_{iH})^2]$, where D_{Hi} is the diversion ratio from Huawei to vendor *i*; D_{iH} is the diversion ratio from vendor *i* to Huawei; M_H is Huawei's gross margin, M_i is vendor *i*'s gross margin, and p_H/p_i is the ratio of Huawei's price to vendor i's price when Huawei is present in the market; *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other. Other represents the combined market shares of all other vendors in the U.S.

[3] The diversion ratio from Huawei to vendor *i* is estimated as follows: $RS_H/(1-RS_i)$, where RS_i is the actual revenue share of vendor *i* in North America in 2018 and RS_H is the actual revenue share of Huawei in North America in 2018**.** The diversion ratio from vendor *i* to Huawei is estimated as $rs_i/(1-rs_H)$; where rs_i is the but-for revenue share of vendor *i* in North America in 2018 and rs_H is the but-for revenue share of Huawei in North America in 2018; and *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other.

[4] The ratio of Huawei's price to vendor *i*'s price is calculated as the ratio of the average sales price of Huawei's LTE FDD RAN products to the average sales price of vendor *i*'s LTE FDD RAN products in Q1 2019. The products used in this calculation include eNodeB macro, eNodeB micro, and eNodeB pico RAN equipment for LTE-FDD, and *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other.

[5] But-for revenue shares of vendors are calculated as follows: $rs_i = RS_i-(rs_H-RS_H)*D_{Hi}$, where RS_i is vendor i's actual revenue share in North America in 2018, RS_H is Huawei's actual revenue share in North America in 2018, rs_H is but-for Huawei's revenue share, D_{Hi} is the diversion ratio from Huawei to vendor *i*, and *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other.

[6] The weighted average price increase is calculated we follows: $pi_{Ericsson}*rs_{Ericsson}+pi_{Nokia}*rs_{Nokia}+pi_{Samsung}*rs_{Samsung}+pi_{ZTE}*rs_{ZTE}+pi_{Other}*rs_{Other}$, where pi_i is the estimated price increase of vendor *i* and rs_i is the actual revenue share of vendor *i* in North America in 2018; *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other.

[7] The diversion ratio from Huawei to vendor *i* calculated using actual revenue shares is equivalent to diversion ratio from Huawei to vendor *i* calcualted using but-for revenue shares; and *i* indexes Ericsson, Nokia, Samsung, ZTE, and Other.

[8] Note that actual revenue shares of vendors in 2018 in North America and but-for revenue shares of vendors in North America are calculated using Dell'Oro data. Vendors' revenue shares are not displayed in the exhibit due to licensing restrictions on the Dell'Oro Group data.

Sources:

[1] "TOTAL GSM," "TOTAL CDMA," "TOTAL WCDMA," "TOTAL LTE," "TOTAL 5G NR," Dell'Oro Group, Q1 2019.

[2] "MOBILE RADIO ACCESS NETWORK – LTE – FDD," Dell'Oro Group, Q1 2019.

[3] "Huawei Investment Holding Co., Ltd., Financials," Available: S&P Capital IQ, McGraw Hill Financial.

[4] "Nokia Corporation," Available: S&P Capital IQ, McGraw Hill Financial.

[5] "Telefonaktiebolaget LM Ericsson," Available: S&P Capital IQ, McGraw Hill Financial.

[6] "Samsung Electronics Co., Ltd., KOSE A005930 Financials," Available: S&P Capital IQ, McGraw Hill Financial.

[7] "ZTE Corporation," Available: S&P Capital IQ, McGraw Hill Financial.

[8] Carl Shapiro, "Unilateral Effects Calculations," last updated October 2010, at http://faculty.haas.berkeley.edu/shapiro/unilateral.pdf, pp. 2-5.

D. STATE OF 5G DEPLOYMENTS IN THE UNITED STATES AND OTHER COUNTRIES

35. In this section I summarize the current status of 5G deployment at the time of this writing. Network deployments of new technology are highly dynamic and the status of network deployments may change rapidly.

i. United States

36. On October 1, 2018, Verizon launched a commercial millimeter wave ("mmW") 5G Fixed Wireless Access ("FWA") service called "Verizon 5G Home" using 28 GHz and 39 GHz bands in parts of Sacramento, Houston, Indianapolis, and Los Angeles. Verizon's network was launched using its own pre-standard 5G technology.[60]

37. On April 3, 2019, Verizon was first in the world to launch commercial 5G mobility (as opposed to FWA) networks. These were deployed in select areas in Chicago and Minneapolis. Verizon's 5G Ultra Wideband networks are accessible via two handsets: Motorola's Moto Z3 with 5G Moto Mod attachment (the attachment is required to access the 5G network), which is available only in the United States,[61] and Samsung's Galaxy S10 5G.[62] Verizon has announced that its 5G mobile networks will be available in 30 cities in 2019. Verizon's 5G network uses 28 GHz spectrum.[63]

38. On December 21, 2018, AT&T commercially launched 5G mobile networks using 39 GHz spectrum in selected areas of 12 cities: Atlanta, Charlotte (NC), Dallas, Houston, Indianapolis, Jacksonville (FL), Louisville (KY), Oklahoma City, New Orleans, Raleigh (NC), San Antonio, and Waco (TX). This service is available via the NETGEAR Nighthawk mobile hotspot device.[64] On June 17, 2019, AT&T started offering 5G services

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[60] 2019 Global Race to 5G Analysys Mason Report, p. 9.

[61] Ed Adamczyk, "Verizon becomes first in the world to activate 5G network," UPI, April 3, 2019, at https://www.upi.com/Top_News/US/2019/04/03/Verizon-becomes-first-in-the-world-to-activate-5G-network/1901554310388/; Ahiza Garcia, "Verizon launches first 5G phone you can use on a 5G network in [sic] US," CNN Business, April 3, 2019, at https://www.cnn.com/2019/04/03/tech/verizon-5g-wireless-chicago-minneapolis/index.html.

[62] Todd Haselton, "The first 5G phone launches today for $1,300," CNBC, May 16, 2019, at https://www.cnbc.com/2019/05/16/samsung-galaxy-s10-5g-launches-on-verizon.html.

[63] Christian de Looper, "Verizon 5G rollout: Here is everything you need to know," Digital Trends, April 4, 2019, at https://www.digitaltrends.com/mobile/verizon-5g-rollout/.

[64] 2019 Global Race to 5G Analysys Mason Report, p. 9.

through its first 5G-capable phone—Samsung Galaxy S10 5G. This device was made available to AT&T's business customers and 5G developers only.[65] AT&T announced that in early 2020 it expects to offer a nationwide 5G footprint using sub-6 GHz spectrum.[66]

39. T-Mobile launched its 5G network on June 28, 2019.[67] T-Mobile's network is available in parts of six cities on the Samsung Galaxy S10 5G. Those cities are Atlanta, Cleveland, Dallas, Las Vegas, Los Angeles, and New York.[68] T-Mobile had announced earlier that it also would be deploying its 5G network on its 600 MHz spectrum.[69] The 5G network that T-Mobile launched on June 28th used mmW spectrum, like Verizon and AT&T. T-Mobile plans on using its low-band spectrum for further deployment.[70]

40. On May 30, 2019, Sprint launched its "true mobile" 5G in four cities across the United States: Atlanta, Dallas-Fort Worth, Houston, and Kansas City. Sprint has also announced plans to roll out 5G networks in parts of Chicago, Los Angeles, New York City, Phoenix, and Washington, D.C. in the coming weeks.[71] Sprint is using 2.5 GHz spectrum for its initial 5G rollout. Sprint announced that its network will be accessible through 5G-enabled LG V50 ThinQ and Samsung Galaxy S10 5G phones. Sprint is also offering 5G connectivity through its mobile hotspot—HTC 5G Hub.[72] In its 5G network, Sprint is

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[65] "AT&T Business Launches Samsung Galaxy S10 5G," AT&T, June 12, 2019, at https://about.att.com/story/2019/samsung_galaxy_s10_5g.html.

[66] "First in the U.S. to Mobile 5G – What's Next? Defining AT&T's Network Path in 2019 and Beyond." AT&T, January 9, 2019, at https://about.att.com/story/2019/2019_and_beyond.html. It is not known from AT&T's statements whether AT&T is planning to deploy 5G in its low-band spectrum, or whether it expects to have obtained mid-band spectrum by that time.

[67] "Imagine a New T-Mobile: 5G for everyone, everywhere," T-Mobile, at https://www.t-mobile.com/5g?icid=WMM_TM_19NETWORK_UHIFVZ1BKZKJARS4J16163_HP.

[68] "T-Mobile to Carry the Samsung Galaxy S10 5G," T-Mobile Press Release, June 25, 2019, at https://www.t-mobile.com/news/samsung-galaxy-s10-5g.

[69] "T-Mobile Building Out 5G in 30 Cities This Year…and That's Just the Start," T-Mobile Press Release, February 26, 2018, at https://www.t-mobile.com/news/mwc-2018-5g.

[70] "T-Mobile to Carry the Samsung Galaxy S10 5G," T-Mobile Press Release, June 25, 2019, at https://www.t-mobile.com/news/samsung-galaxy-s10-5g.

[71] "Sprint Lights Up True Mobile 5G in Atlanta, Dallas-Fort Worth, Houston and Kansas City," Sprint Corporation Press Release, May 30, 2019, at https://newsroom.sprint.com/sprint-lights-up-true-mobile-5g-in-atlanta-dallas-fort-worth-houston-and-kansas-city.htm.

[72] "Sprint Lights Up True Mobile 5G in Atlanta, Dallas-Fort Worth, Houston and Kansas City," Sprint Corporation Press Release, May 30, 2019, at https://newsroom.sprint.com/sprint-lights-up-true-mobile-5g-in-atlanta-dallas-fort-worth-houston-and-kansas-city.htm; "Sprint U.S. Exclusive, HTC 5G Hub Delivers 5G Speed for Up to 20 Devices," Sprint, February 25, 2019, at https://newsroom.sprint.com/sprint-us-exclusive-htc-5g-hub-delivers-5g-speed-for-up-to-20-devices.htm.

deploying Massive MIMO provided by Ericsson, which it has deployed on its existing 4G cell sites and which are capable of simultaneously providing 4G LTE-Advanced and 5G service.[73]

ii. Australia

41. In December 2018, four mobile carriers in Australia won spectrum licenses in the 3.6 GHz band, which were allocated for 5G by the Australian Communication and Media Authority.[74] On May 22, 2019, Telstra launched its first 5G device—HTC 5G Hub—that works on Telstra's 5G mobile network in parts of 10 Australian cities.[75] It is expected that Telstra's 5G mobile network will reach at least 35 Australian cities by June 2020.[76] On May 28th, Telstra launched its first 5G-capable handset—Samsung Galaxy S10 5G.[77]

42. Optus has launched 5G FWA networks which are available to select customers in Brisbane, Adelaide, Perth, and some other areas. Optus plans to deploy over 1,000 5G sites by March 2020.[78]

43. Vodafone will be rolling out its 5G network in 2020.[79]

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[73] "Sprint Lights Up True Mobile 5G in Atlanta, Dallas-Fort Worth, Houston and Kansas City," Sprint Corporation Press Release, May 30, 2019, at https://newsroom.sprint.com/sprint-lights-up-true-mobile-5g-in-atlanta-dallas-fort-worth-houston-and-kansas-city.htm.

[74] The 5G licenses allocated in the spectrum auction will start in March 2020. Juan Pedro Tomás, "Telecom Regulator ACMA said Australia raised over $615 million during the process," RCR Wireless, December 10, 2018, at https://www.rcrwireless.com/20181210/5g/four-australian-carriers-secure-5g-spectrum-band.

[75] "Telstra launches Australia's first 5G mobile device," Telstra Press Release, May 22, 2019, at https://www.telstra.com.au/aboutus/media/media-releases/Telstra_launches_Australias_first_5G_mobile_device; Jacqui Dent, "When can you get 5G in Australia," Whistle Out, June 17, 2019, at https://www.whistleout.com.au/MobilePhones/Guides/when-can-you-get-5G-in-Australia.

[76] "Australia's first 5G service goes live," Ericsson Press Release, May 22, 2019, at https://www.ericsson.com/en/news/2019/6/5g-live-in-australia-with-telstra.

[77] Kevin Teoh, "Australia's first 5G smartphone, the Samsung Galaxy S10 5G, is now in stores," Telstra Exchange, May 28, 2019, at https://exchange.telstra.com.au/australias-first-5g-smartphone-samsung-galaxy-s10-5g-now-in-stores/.

[78] Tim Fisher, "When Is 5G Coming to Australia? (Updated for 2019)," July 1, 2019, Lifewire, at https://www.lifewire.com/5g-australia-4583137.

[79] Jacqui Dent, "When can you get 5G in Australia," Whistle Out, June 17, 2019, at https://www.whistleout.com.au/MobilePhones/Guides/when-can-you-get-5G-in-Australia.

iii. China

44. China has yet to launch a commercial 5G network. In December 2018, the Chinese Ministry of Industry and Information Technology ("MIIT") distributed spectrum licenses in the 3.5 – 3.6 GHz, 3.4 – 3.5 GHz, 2.515 – 2.675 GHz, and 4.8 – 4.9 GHz bands to the three major Chinese carriers for 5G trials.[80] On June 6, 2019, MITT awarded commercial licenses to the same companies in the same bands.[81] China Mobile has announced plans to roll out 5G networks in more than 50 cities by the end of 2019, ahead of the earlier Chinese timeline, which planned for commercial 5G rollout in 2020.[82]

iv. Japan

45. No Japanese telecommunications company has launched a 5G network at the time of this report. In April 2019, Japanese regulators allocated mid-band and high-band 5G spectrum (3.6 GHz – 4.6 GHz and 27.0 GHz –29.5 GHz) to telecommunications companies, and Japanese carriers plan to begin commercial 5G services in 2020.[83] The conditions of Japan's spectrum allocation require these carriers to deploy in every prefecture within two years.[84] The earliest estimates, from KDDI and Softbank, project launches of 5G networks

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[80] "China issues 5G trial spectrum permits," *Telegeography*, December 10, 2018, at https://www.telegeography.com/products/commsupdate/articles/2018/12/10/china-issues-5g-trial-spectrum-permits/index.html. "MIIT awards 5G licences to three MNOs plus cable operator," *Telegeography*, June 6, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/06/06/miit-awards-5g-licences-to-three-mnos-plus-cable-operator/index.html.

[81] "MIIT awards 5G licences to three MNOs plus cable operator," *Telegeography*, June 6, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/06/06/miit-awards-5g-licences-to-three-mnos-plus-cable-operator/index.html.

[82] Juan Pedro Tomás, "China Mobile to launch 5G in 50 cities across China by end-2019," *RCR Wireless*, June 26, 2019, at https://www.rcrwireless.com/20190626/5g/china-mobile-launch-5g-50-cities-china-end-2019.

[83] "MIC approves allocation of 5G spectrum to Japanese operators, with conditions," *Telegeography*, April 11, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/04/11/mic-approves-allocation-of-5g-spectrum-to-japanese-operators-with-conditions/index.html.

[84] "MIC approves allocation of 5G spectrum to Japanese operators, with conditions," *Telegeography*, April 11, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/04/11/mic-approves-allocation-of-5g-spectrum-to-japanese-operators-with-conditions/index.html.

in March 2020.[85] While Japan's timeline is later than those of the United States and South Korea, Japan has now allocated both mid- and high-band spectrum for 5G use.[86]

v. South Korea

46. On December 1, 2018, South Korean carriers SK Telecom, KT, and LG Uplus launched 5G Fixed Wireless Access ("FWA") services. These services were launched simultaneously by the three carriers in selected locations to select individuals.[87] On April 3, 2019, SK Telecom, KT, and LG Uplus opened commercial wireless 5G network to the general public. The networks became accessible to other subscribers on April 5, 2019, when Samsung's 5G smartphone Galaxy S10 5G was launched in South Korea.[88] As of June 12, 2019, the three South Korean carriers announced that they had collectively enrolled 1 million 5G subscribers.[89] Each of the South Korean carriers holds large spectrum blocks in both mid- and high-band spectrum.[90]

vi. Switzerland

47. On April 4, 2019 Swiss telecommunications operator Sunrise launched FWA 5G in more than 150 cities/villages.[91] Sunrise's 5G network will be available via its Sunrise Internet

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[85] "MIC approves allocation of 5G spectrum to Japanese operators, with conditions," *Telegeography*, April 11, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/04/11/mic-approves-allocation-of-5g-spectrum-to-japanese-operators-with-conditions/.

[86] "MIC approves allocation of 5G spectrum to Japanese operators, with conditions," *Telegeography*, April 11, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/04/11/mic-approves-allocation-of-5g-spectrum-to-japanese-operators-with-conditions/.

[87] *2019 Global Race to 5G Analysys Mason Report*, pp. 9-10; Tim Fischer, "When Is 5G Coming to South Korea? (Updated for 2019)," Lifewire, April 5, 2019, at https://www.lifewire.com/5g-south-korea-4583813.

[88] Tim Fischer, "When Is 5G Coming to South Korea? (Updated for 2019)," Lifewire, April 5, 2019, at https://www.lifewire.com/5g-south-korea-4583813; Nidhi Singh, "Here's the World's First Country to Launch 5G Services," Entrepreneur Asia Pacific, April 5 2019, at https://www.entrepreneur.com/article/331801.

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[90] *2019 Global Race to 5G Analysys Mason Report*, pp. 9, 67.

[91] "'5G for People' has started: First Sunrise customers are using 5G," Sunrise Press Release, April 4, 2019, at https://e3.marco.ch/publish/sunrise/821_3894/20190404_MM_First_5G_Pioneer_EN.pdf.

Box 5G device.[92] Sunrise also launched 5G networks on April 17, 2019 in 54 cities in Switzerland. Sunrise offers 5G smartphones through the Huawei Mate 20 X.[93]

48. Swisscom is offering connection to its 5G network through three mobile phones: the Oppo Reno 5G, LG V50 ThinQ, and Samsung Galaxy S10 5G.[94] Swisscom's network is the first large-scale commercial 5G network in Europe to support commercially available smartphones, and it was launched in partnership with Ericsson.[95] Both Sunrise and Swisscom launched their networks on spectrum from a February 2019 auction, in which both Sunrise and Swisscom purchased spectrum in the 700 MHz, 1400 MHz, and 3500 MHz (3.5 GHz) ranges.[96]

vii. United Kingdom

49. In the United Kingdom, carrier EE launched mobile commercial 5G networks in parts of six major cities at the end of May 2019.[97] EE offers 5G service through the OnePlus 7 Pro 5G, Oppo Reno 5G, LG V50 ThinQ, and Samsung Galaxy S10 5G phones.[98] EE's 5G networks are also available via either mobile broadband device or home broadband router.[99] Vodafone launched 5G commercial networks in seven British cities on July 3, 2019. Vodafone's 5G networks are accessible via two mobile phones, the Xiaomi Mi Mix

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[92] "Sunrise unveils 5G plans," *TeleGeography*, February 21, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/02/21/sunrise-unveils-5g-plans/. Sunrise Internet Box 5G device is not yet available for purchase at Sunrise's website. See "Hotspots," Sunrise, at https://www.sunrise.ch/en/residential/geraete/hotspots.html#/.

[93] "Sunrise and Huawei Jointly Announce First 5G Smartphone in Switzerland," Huawei Press Release, May 8, 2019, at https://www.huawei.com/en/press-events/news/2019/5/sunrise-huawei-jointly-announce-first-5g-smartphone; Juan Pedro Tomás, "Ericsson, Swisscom launch commercial 5G network in Switzerland," RCWireless News, April 17, 2019, at https://www.rcrwireless.com/20190417/5g/ericsson-swisscom-5g.

[94] Jeremy Horwitz, "Swisscom debuts Europe's first commercial 5G service with May phone launch," April 10, 2019, at https://venturebeat.com/2019/04/10/swisscom-debuts-europes-first-commercial-5g-service-with-may-phone-launch/.

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[97] "EE launches 5G in six cities," *Telegeography*, May 31, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/05/31/ee-launches-5g-in-six-cities/index.html.

[98] "Discover 5G," *EE*, at https://ee.co.uk/why-ee/5g-on-ee.

[99] "EE launches 5G in six cities," *Telegeography*, May 31, 2019, at https://www.telegeography.com/products/commsupdate/articles/2019/05/31/ee-launches-5g-in-six-cities/index.html.

3 and the Samsung S10 5G, and a 5G router.[100] Carrier Three is set to launch in London in August.[101]

50. Ofcom, the British agency that regulates spectrum, auctioned 2.3 GHz and 3.4 GHz spectrum in 2018 and has plans to award the 700 MHz low-band and 3.6-3.8 GHz mid-bands in December 2019.[102]

viii. United Arab Emirates

51. In November 2018, the Telecommunications Regulatory Authority ("TRA") of the United Arab Emirates ("UAE") issued 5G spectrum in the mid band (3.3-3.8 GHz) to Etisalat and Du, the country's two largest telecommunications companies.[103] Both Etisalat and Du are selling ZTE's Axon 10 Pro smartphone, which is 5G capable, but neither Etisalat nor Du plan to launch commercial 5G services until 2020.[104] Du plans to launch its service in late 2019 and Etisalat plans to launch 5G in 2020.[105]

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[100] Paul Sandle, "Vodafone launches 5G in Britain with unlimited data plans," *Reuters*, July 3, 2019, at https://uk.reuters.com/article/us-vodafone-5g-britain/vodafone-launches-5g-in-britain-with-unlimited-data-plans-idUKKCN1TY2EC.

[101] "UK mobile operator Three to launch 5G broadband in August," *Reuters*, June 9, 2019, at https://www.reuters.com/article/us-three-5g/uk-mobile-operator-three-to-launch-5g-broadband-in-august-idUSKCN1TA0V4.

[102] "Ofcom's Annual Plan: Our programme of work for 2019/20," Ofcom, March 25, 2019, ¶¶ 2.8, 3.8.

[103] "TRA confirms UAE 5G spectrum allocations," *Telegeography*, November 19, 2018, at https://www.telegeography.com/products/commsupdate/articles/2018/11/19/tra-confirms-uae-5g-spectrum-allocations/index.html.

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[105] "Etisalat Completes the Fastest 5G," Etisalat Press Release, https://www.etisalat.ae/en/about-us/media_center/press_releases/etisalat_g.jsp. "du's 5G Experience Goes Live This Ramadan," Du Press Release, May 21, 2019, at https://www.du.ae/about/media-centre/newsdetail/du-5g-experience-goes-live-this-ramadan.